Attention Allocation During the Observation of Biological Motion: An EEG study

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By

Themis Efthimiou, BSc

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Abstract:

The processing of observed biological motion that is the movement of biological organisms has an important role in animals' vigilance and survival. For humans, it is also implicated in the development of social cognition and communication, with infants showing preferential attention towards motion from an early age. Further, adults can extract a broad range of social information from the biological motion of human figures represented by dots of light (point-light displays), that contain kinematic, structural and dynamic information. From this information, humans can identify individual actors, their sex, emotional state (angry, happy, and sad) and walking direction even when obfuscated by additional noise. The processing of biological motion draws on different cognitive systems such as working memory, selective attention and sensorimotor processing. Humans demonstrate an attentional bias towards human forms and biological motion, compared to other non-biological stimuli, and the observation of biological movement activates sensorimotor cortical regions. Previous research has used EEG to measure mu frequency (~ 8-13 Hz) changes and to infer the activation of sensorimotor regions during biological movement observation. This sensorimotor activation is thought to be an indication of online movement simulation. It has been demonstrated that top-down attentional processes modulate the engagement of sensorimotor simulation during movement observation. What remains unknown is whether biological motion exogenously captures spatial attention and, in turn, modulates sensorimotor simulation; the current study sought to explore this question.

In the current study, I used an attentional bias paradigm where movement and control point-light displays are presented laterally and simultaneously as irrelevant cues. Relatively decreased reaction times to subsequent targets that appear in the same location as a cue reflects preferential processing of that preceding cue. I simultaneously recorded EEG and calculated mu frequency changes at both central and occipital electrode locations. I find decreased

reaction times and an increase in correct responses to targets that replace the scrambled point light display (PLD), which represents non-biological motion, compared to targets that replaced the coherent PLD representing biological movement. In addition, EEG analysis revealed a left hemisphere bias, with post hoc analysis revealing this bias is driven by the central electrodes; with a larger desynchronisation in the left central electrode compared to the right central electrode, whereas, occipital alpha was desynchronised symmetrically. Together, the behavioural and EEG findings suggest an inhibition of return (IOR) effect.

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Introduction

Humans are highly social creatures with a visual perception system capable of extracting a range of social information from non-verbal cues (e.g., faces and bodies) (Mehrabian, 2017). There is a large body of work and a variety of methods that have been used to investigate the perception of static images of non-verbal cues and how they are processed (Krumhuber, Kappas, & Manstead, 2013; Peelen & Downing, 2007). Infants have been shown to prefer attending to stimuli that are inherently social (e.g., faces) compared to stimuli which are not (e.g., objects). By presenting each stimulus (social and non-social) in the infant's visual field and measuring which stimulus the infant engages in and for how long. It has been demonstrated that infants stare at the social stimuli for a longer period compared to the non-social stimuli, which suggests infants can discriminate between the two and have a preference for one over the other (Simion, Regolin, & Bulf, 2008). In adult populations, the recognition of social information has been explored using standard recognition tasks, by employing forced choices from a list of emotional labels or judgement of emotional intensity when observing static images of faces, bodies or body parts. By displaying participants static images of faces, expressing different emotional states (anger, happiness, sadness) and asking participants to identify the facial expressions they can with high levels of accuracy identify emotional states (Ekman, 1970; Vuilleumier & Pourtois, 2007). Similarly, it has been shown that when participants observe static images of dots of light that are organised to appear like a human figure, they are capable of accurately judging the emotional state of the figure (Atkinson, Tunstall, & Dittrich, 2007; Coulson, 2004; De Gelder & Hadjikhani, 2006). While static images of faces and bodies provide a wealth of information, the motion also conveys social information; specifically, the motion of living organisms, biological motion. Understanding these cognitive mechanisms and brain processes are key in refining theories of how biological motion is processed (Blake & Shiffrar, 2007). Understanding these cognitive mechanisms and

brain processes are key in refining theories of how biological motion is processed (Blake & Shiffrar, 2007) and neuroergonomic evaluations (Thompson & Parasuraman, 2012).

Research exploring the processing of biological motion has used Point Light Displays (PLDs). PLDs were developed by Johansson (1973) by placing light bulbs on key joints of an actor who would perform complex movements (e.g., walking, knocking, dancing) while being recorded in the dark and against a black screen. This process results in a video recording of eleven moving points (dots) of light on a black background with a human form known as point-light walkers. More recently, new techniques have been developed, using video or motion capture information to generate PLDs that have aided in the development of a variety of PLD databases containing different actions (jumping, knocking, cycling), social interactions of PLDs of actors talking or fighting, and conducting these behaviours in different emotional states (angry, happy, neutral) (for review, see, van Boxtel & Lu, 2013). It has been proposed by Aaen-Stockdale, Thompson, Hess, and Troje (2008) that biological motion processing takes place in two ways. First, global processing of the PLD that is the entire form of the walker takes places, the motion and the dynamically changing shape while in motion. Second, local processing of specific joints or dots representing the body part of the figure (e.g., limbs). Further, three forms of visual information are displayed when a PLD enacts biological motion — first, structural or form information which changes over time. Second, kinematic information; the velocity of movement, acceleration and the displacement of motion. Last, dynamic information of the specific motion enacted in regards to mass and force (van Boxtel & Lu, 2013).

PLDs have been used in a broad range of research as they offer many advantages compared to using the whole form of the actor. First, all forms of visual information can be easily manipulated and generated algorithmically. In addition, a PLD mainly contains motion information with few cues about the body structure, facial expressions, shadows, hair, clothing

and other visual information not related to movement that may interfere with the extraction of social and motion relevant information. Research using PLDs demonstrates that participants are capable of identifying individuals from the PLDs gait (Janssen et al., 2008) and the actor's emotion (Parkinson, Walker, Memmi, & Wheatley, 2017). In addition, participants can distinguish the actors sex (Pollick, Kay, Heim, & Stringer, 2005), walking pattern (Ding, Yin, Shui, Zhou, & Shen, 2017) and the actors intent (Cohen, Morelli, & Scott, 2008) making it a powerful tool to understand the processing of movement (Hill & Pollick, 2000).

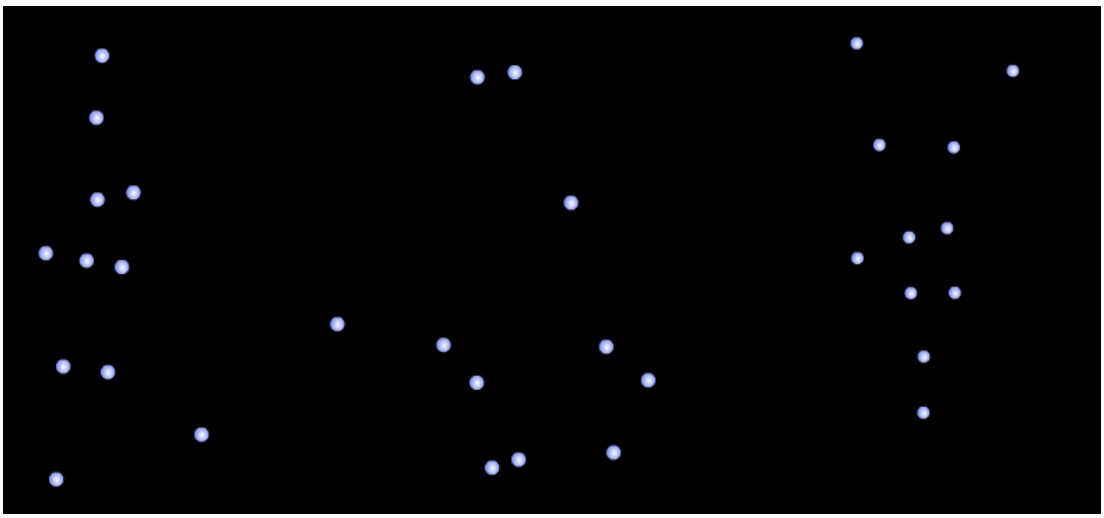


Fig 1. A static example of Point Light Displays generated by Troje and Westhoff, (2006) database and paused on the first frame. The PLDs consist of 11-dots representing each joint of a human figure. The first (left) image represents a coherent PLD directed toward the left from a sagittal view. The centre image is the same scrambled PLD where each point (dot) has been randomly positioned. The final (right) image displays the coherent PLD that has been inverted.

The detection and perception of biological motion remain relatively well preserved throughout a humans life span (Norman, Payton, Long, & Hawkes, 2004). Individuals with William syndrome, who experience visuospatial deficits and show deficits in other types of motion processing, can accurate identify different actions (jumping, slipping on a banana), identify the PLD walk direction when embedded in a dynamic mask (Jordan, Reiss, Hoffman, & Landau, 2002; Reiss, Hoffman, & Landau, 2005). In addition, individuals diagnosed with

cortical blindness after anoxia-induced bilateral striate damage (who experience severe impairment in the visual processing of colour, shapes, faces, and the recognition of objects) can still identify biological motion. Nicolas and colleagues (2016) report on a patient who was experiencing cortical blindness, named BC. BC was unable to discern individual coherent static or moving PLDs accurately. However, when presented in pairs, BC made eye movements towards the moving PLD, but not when the PLDs were static. In neurotypical populations, biological motion can be detected and processed in both central and peripheral vision (Thompson, Hansen, Hess, & Troje, 2007). The PLD is also recognisable when there are additional dots that embed the PLD and act as 'noise' to make recognition of the PLD difficult as the PLDs form is less visible. The addition of noise can be static or moving (dynamic) and the walking direction of a point-light walker can still be discerned when the noise is dynamic (Aaen-Stockdale et al., 2008). Although, when the PLDs orientation is inverted, participants have reduced accuracy when identifying the PLDs social information such as walk direction, sex, and action (Barclay, Cutting, & Kozlowski, 1978; Pavlova & Sokolov, 2000; Troje, 2003; Troje & Westhoff, 2006). Another manipulation of PLD is by scrambling them, this results in the local motion remaining intact, but the processing of the global motion of the PLD is disrupted. This effect disrupts the shape of the figure and contains no configural information. Although, if presented upright, participants viewing scrambled PLDs can still discern its walking direction (Troje & Westhoff, 2006). The directional information is suggested to be carried by local motion of the PLD, specifically the dots representing the walker's feet and can be extracted within 100 ms (Hirai, Saunders, & Troje, 2011; Troje & Westhoff, 2006a). While biological motion processing can be disrupted, it remains largely intact and robust in various contexts, suggesting it has a special status and rapid, innate mechanism to support it.

The ability to process biological motion from PLDs is also seen in a variety of species with an innate preference towards the movement of living organisms (Blake, 1993; Oram &

Perrett, 1996; Watanabe, Sakamoto, & Wakita, 1995). Newly hatched chicks innately display sensitivity to the walking direction displayed by PLDs, even when having no prior exposure to any other visual experience (Vallortigara & Regolin, 2006; Vallortigara, Regolin, & Marconato, 2005). Human visual perception demonstrates this same preference; adults can rapidly detect biological motion within 200 ms (Johansson, 1973). Human new-borns begin to prefer looking at biological motion within the first few days of being born (Simion et al., 2008) over the next two years of life this preference becomes more pronounced (Sifre et al., 2018). By three months, infants can discriminate between walking motions such as running (Booth, Bertenthal, & Pinto, 2002). At six months infants can distinguish between upright and inverted PLDs with a preference for upright walkers and can recognise walking direction from a sagittal view (Bertenthal, Proffitt, & Cutting, 1984; Fox & McDaniel, 1982; Kuhlmeier, Troje, & Lee, 2010). The preference and rapid detection to biological motion have been argued to play an important role in human evolutionary survival by being able to quickly notice and respond to predators (Ewert, 1987).

The perception of biological motion has been implicated in the development of social cognition (Pavlova, 2012). Infants can learn by attending to social signals such as facial expressions, gaze direction, gestures and intentions underlying actions (Blakemore & Decety, 2001; Spencer, O'Brien, Johnston, & Hill, 2006; Yoon & Johnson, 2009). This ability appears to be universal with adults from remote cultures recognising the emotional content of actors in PLDs from Western nations and, in turn, participants from Western nations recognising the emotional content of the PLDs recorded from the actors of those remote cultures (Parkinson et al., 2017). The role of social cognition in biological motion processing also comes from studying neurodivergent populations. Individuals who are diagnosed with autism spectrum disorder (ASD) demonstrate impaired biological motion processing (van Boxtel, Dapretto, & Lu, 2016), specifically difficulty in discerning the emotional state displayed by PLDs (Parron

et al., 2008) and a difference in activation of the neural mechanisms involved during the observation of biological motion (Herrington et al., 2007; McKay et al., 2012). Although this difference is suggested to be in the global processing of the PLD, whereas local motion processing is unaffected (Happé & Frith, 2006). van Boxtel, Peng, Su, and Lu (2017) conducted three studies correlating ASD traits with neurotypical participants ability to identify PLD in different settings, such as hidden behind dynamic noise, inverted, and performing a social interaction. ASD traits did not correlate with identifying walking direction. However, ASD traits correlate with a reduced preference for upright walkers in comparison with inverted walkers, suggesting there was a reduction in global form processing. Last, during the observation of social interactions between PLDs, participants with high ASD traits were less capable of distinguishing between interactive and non-interactive actions. Taken together, these studies demonstrate that social information such as emotional content and actions displayed in PLDs is linked with social cognitive abilities, and when these abilities are inhibited the extraction of this social information is reduced.

In this section, it has been explained that biological motion processing plays a significant role in the survival of animals and aids in supporting social functions. In addition, it is preferentially selected for and remains relatively well preserved in neurodivergent populations who experience visual deficits, suggesting it is robust and innate. The following section moves on to consider how the processing of biological motion is facilitated by attentional and sensorimotor mechanisms in detecting and recognising social information carried by in biological motion. In addition, it will consider in tandem with the unique neural mechanisms that have been posited to have developed to favour and rapidly process biological information over other forms, like that found during facial processing (Kanwisher, 2000; Slaughter, Stone, & Reed, 2004). A range of neuroimaging, neurostimulation techniques, such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), transcranial

magnetic stimulation (TMS) has been used to aid in understanding the neural correlates of biological motion detection and understanding the action, emotion, and intent displayed by PLDs.

Attention and Sensorimotor engagement in biological motion processing:

Human bodies, body parts and faces appear to be preferentially attended to compared to non-biological stimuli. This has been explored primarily with static images of whole bodies, body parts as silhouettes or stick figures of human bodies (e.g., Ro, Friggel, & Lavie, 2007; Stein, Sterzer, & Peelen, 2012). For example, Downing, Bray, Rogers, and Childs (2004) demonstrated that human bodies are preferentially attended compared to non-biological stimuli. In this study, an inattentional blindness task was used: participants have a fixation cross displayed and asked to judge if the vertical or horizontal line was longer. A stimulus would appear in participants peripheral vision; the stimuli consisted of silhouettes or stick figures of human bodies, body parts or objects. For the first part of the experiment, participants were informed of the task but were not informed of the stimulus, and it appeared unexpectedly. Only the first trials were analysed to examine whether the biological stimuli would influence the subject's performance on the task, when unaware that it would appear and without repeated exposure. In later trials, participants were asked to respond to the line length task and stimulus. Finally, participants were asked to respond to the stimulus only. Participants were significantly better able to detect a human figure relative to the control stimuli. This study was the first to reveal that even when unexpected and irrelevant to the task, human bodies are prioritised for attentional selection.

The salience of biological motion processing has led to the exploration of its influence in spatial attention, that is the ability to process sensory input in space selectively. Two forms of spatial attention are involved in modulating the processing and perception of information: endogenous and exogenous. Endogenous attention is when the observer attends to a region

in space, shifting their gaze. Endogenous mechanisms are purposeful and require effortful orienting caused by instructive information at another location. In contrast, exogenous processing is caused reflexively by a salient sensory event, such as a flash in the periphery of visual space. Different paradigms have been used to investigate attention during the observation of biological motion, such as visual search tasks (Treisman & Souther, 1985) the flanker task (Eriksen & Eriksen, 1974) and different versions of the Posner cueing task (Posner, 1980). When examining spatial attention in biological motion processing, both global and local information are capable of influencing spatial attention. Local information such as walk direction, hand pointing and gaze can shift the observer towards the location signalled by the stimulus (Driver et al., 1999; Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008; Langten, Watt, & Bruce, 2000; Tipples, 2002). Thornton & Vuong (2004) demonstrated that the global motion of a coherent PLD exogenously influences the observer's behaviour, using a flanker task. This task assesses incidental processing; the observer is asked to respond to a central PLD which is either presented alone or with additional stimuli next to it. In this study, the coherent PLD was presented from a sagittal view and simulated walking. In the periphery, two additional coherent PLDs appeared, facing the same direction (congruent) or the opposite direction (incongruent). Participants responded faster when a single walker appeared and slowest when incongruent walkers were presented in with the central walker. The study demonstrates that even when the participants are told to ignore the peripheral PLDs, they are still processed, and their global direction competes with the observer's attention to the central PLD. Thus, biological motion is capable of influencing the observer's attention and influence their behavioural performance.

The exploration of local motion influencing the observer's attention has been explored using modified Posner cueing paradigms (Posner, 1980). In an endogenous paradigm, a participant would be shown an informative cue directing the observer's attention. For example,

a right or left arrow displayed centrally would direct the observer's attention to that peripheral side. This orienting effect generally leads to enhanced processing of the target that appears in the directed location resulting in faster RTs compared to when the target appears in the unattended area (e.g., Cohen, Bolanowski, & Verrillo, 2005; Müller & Rabbitt, 1989). Whereas in an exogenous orienting Posner paradigm, the participant's attention is implicitly orientated by non-informative peripheral cues, in this case, participants are told to fixate their vision centrally, and cues should be ignored. These cues will appear at either side of the observer's peripheral vision, followed by a target that participants respond to. This paradigm can either facilitate or inhibit the participant's response time (Miles, Poliakoff, & Brown, 2008). Facilitation takes place when the target appears at the same location as the cue, and observers respond with reduced RTs. However, when there is a long stimulus onset asynchrony (SOA) between cue and target (approximately 300 ms in vision) RTs are slower to that cued location compared to novel locations, this phenomenon is described as inhibition of return (IOR) (Klein & Ivanoff, 2005; Posner & Cohen, 1984). This has been explained as a method of saving attentional resources by inhibiting attentional reorientation to space that has already been viewed (Posner, Rafal, Choate, & Vaughan, 1985).

Selective attention to the perceptual elements of objects, such as its location (Corbetta & Shulman, 2002), motion (O'Craven, Downing, & Kanwisher, 1999) and colour (Clark et al., 1997) can modulate neural responses in the brain regions in which the observed information is processed. Thus, there is a growing view that attention can also modulate the activity of brain regions that respond to biological motion. Shi, Weng, He, and Jiang, (2010) displayed a coherent human PLD centrally fixed, that walked from a sagittal view to participants, facing the left or right side of the monitor. After a short period, the PLD disappeared, and a Gabor patch was briefly presented clockwise or anti-clockwise in the observers left or right peripheral visual space. Participants had to discern the Gabor patches orientation and performance was

better when the Gabor patch appeared in the same direction the PLD walked. This finding remained when the coherent PLD was of an animal, however, was not present when the PLD was inverted, static or a PLD of an object. This study is the first to demonstrate that information from a PLD can endogenously shift the observer's visuo-spatial attention.

The rapid detection of biologically relevant information is suggested to begin in the extrastriate visual cortex and posterior inferior temporal sulcus (pITS) (Thompson & Parasuraman, 2012). There are two specific regions in the pITS which show preference to biological compared to non-biological information. First, the extrastriate body area (EBA) which fMRI studies have consistently found active during the perception of whole human bodies, human body parts and the imagined movements of body parts, independent of whether they are static or moving (Astafiev, Stanley, Shulman, & Corbetta, 2004; De Bellis, Trojano, Errico, Grossi, & Conson, 2017; Downing, Jiang, Shuman, & Kanwisher, 2001). Second, the area MT+ which preferentially responds towards the biological motion of displayed by PLDs with a human form rather than PLDs that have their form scrambled (see fig. 1) (Grossman, 2010; Jastorff & Orban, 2009; Peelen et al., 2006). This preference in response to a coherent compared to scramble PLD, suggests the MT+ region is involved in the processing of the form, that is portraying the motion (Peelen, Wiggett, & Downing, 2006) with the integration of the recognition of the action following from this (Jastorff & Orban, 2009).

The superior temporal sulcus (STS) shows increased activity during observation of movement, with lesions to this area impairing the detection and identification of biological motion, suggesting it plays a significant role in its processing (Grossman et al., 2000; Herrington, Nymberg, & Schultz, 2011; Saygin, 2007). In addition, neurodivergent populations, such as individuals diagnosed with ASD, demonstrate similar activity in the STS as neurotypical populations when observing coherent PLDs compared to scrambled PLDs. However, the ASD population show reduced STS activity compared to the neurotypical

population when the PLDs display emotional content or actions (Alaerts, Swinnen, & Wenderoth, 2017). Thus, suggesting the STS has a function in encoding social information rather than the global or local motion or PLDs. The STS has been demonstrated to play different roles for different aspects of social perception, such as mentalising, face processing and social reward processes (Allison, Puce, & McCarthy, 2000; Pelphrey, Shultz, Hudac, & Vander Wyk, 2011). In addition, the posterior superior temporal sulcus (pSTS) dorsal to the pITS is suggested to be more specialised for processing biological motion during observation of recordings human movement and human form PLDs (Decety & Grèzes, 2006; Grèzes et al., 2001; Grossman et al., 2000; Peelen & Downing, 2007; Pelphrey, Morris, Michelich, Allison, & McCarthy, 2005; Servos, 2002). Disrupting the pSTS using repetitive transcranial magnetic stimulation (rTMS) effects recognition of upright human form PLDs. However, the same was not true when rTMS was applied over the visual motion-sensitive area (Grossman, Battelli, & Pascual Leone, 2005). The pSTS provides visual input to the frontoparietal regions, which are suggested to be part of an Action Observation Network (AON) (Cattaneo & Rizzolatti, 2009). The AON consists of different brain regions that are suggested to become active during the observation of actions, the inferior frontal gyrus, dorsal and ventral motor cortex (dPMC, vPMC), the supplementary motor area (SMA), the inferior parietal lobe (IPL), the superior parietal lobe (SPL) and the primary sensory cortex (SI) (Caspers, Zilles, Laird, & Eickhoff, 2010). Together the AON has been noted to play a critical role during the observation of others performing actions by integrating the observed actions of others into one's motor system. The processing of biological motion must be a multi-stage process, detecting the form (e.g., walker or body), then motion and the socially relevant information that is integrated by the regions included in the AON.

The integration of observed motion enacting different action has been explained by theories of embodied cognition, which can be summarised as the position that perception and

cognition are linked to the body and how one's body is used (Barsalou, 2003; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2005). Specifically, when observing actions being carried out, it has been suggested that they are understood through a simulation process (Barsalou, 2008; Niedenthal, 2007; Wood, Rychlowska, Korb, & Niedenthal, 2016). This simulation theory (Gallese & Goldman, 1998) posits that when an action is observed, passive and automatic neural mechanisms simulate the observed action, engaging the sensorimotor system. An example of this is emotional mimicry were individuals match each other's emotional expression, which is suggested to be a simulation of the emotions another is experiencing (Dimberg, Thunberg, & Elmehed, 2000; Wood et al., 2016). Thus, it can be argued that during the observation of biological motion, mirror neurons in these regions which respond to executed and observed action (Caspers et al., 2010), become engaged and the simulation process in recognising the social information carried by the model observed.

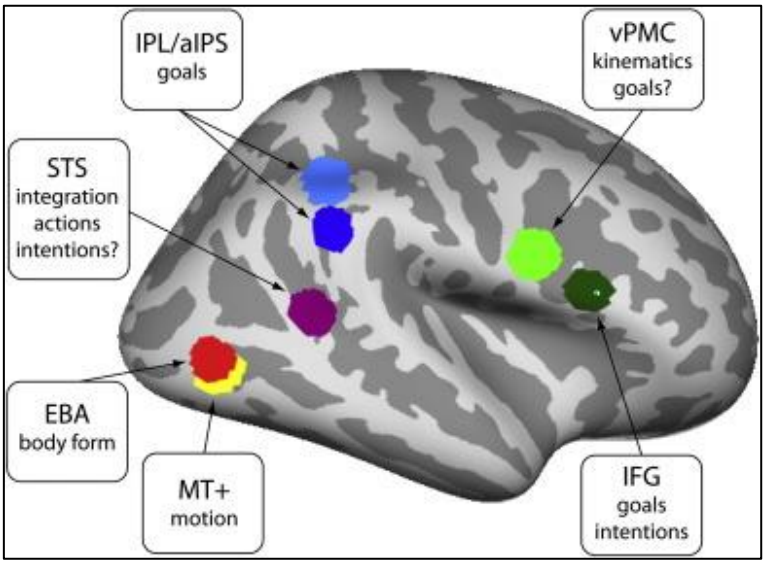


Fig 2. Brain regions involved in action observation, shown on an inflated surface representation of the right hemisphere of the template brain. Light grey areas represent gyri, and dark grey areas represent sulci. Taken from Thompson and Parasuraman (2012).

The aforementioned neuroimaging techniques have aided in defining the brain regions that form the network that allows for the detection and understanding of observed actions

from bodies. However, this provides little understanding of how different cortical regions become engaged temporally. For this, electroencephalography (EEG) has been used to investigate the timings of neural activation during the observation of PLDs enacting biological motion. EEG is a non-invasive technique that involves placing electrodes on a participant's scalp and directly measuring the electrical activity. This is a relatively inexpensive technique that provides high temporal resolution, being limited only by the sample rate.

However, EEG provides a poor spatial resolution; thus, it is best used to answer questions regarding the temporal changes. The raw data extracted from EEG recordings contain neural responses that are associated with specific sensory and motor events. EEG can be analysed in the time or frequency domain. The former giving you event-related potentials (ERPs) the latter giving you frequency information. These neural responses are so-called ERPs, as they are multiple averaged electrical potentials that are related to a specific event. The changes in neural activity on the onset of an event can be analysed using a simple averaging technique (and other techniques, such as time-frequency analysis) (Luck, 2005) allowing for the exploration of temporal changes.

Research using EEG recording has allowed for the exploration of temporal changes in cortical activity during the observation of whole-bodies or anatomical body parts. A range of research has revealed that biologically relevant stimuli induced faster changes in cortical activity compared to non-biologically relevant stimuli (Engell & McCarthy, 2014; Meeren, Van Heijnsbergen, & De Gelder, 2005; Reid, Hoehl, & Striano, 2006). Jokisch et al., (2005) presented participants with an upright coherent PLD, an inverted coherent PLD or a scrambled PLD with stimulus presentation and onset of motion taking place in parallel. In all conditions, changes in amplitude at parietal and occipital electrodes was demonstrated at 180 ms in condition, with a greater amplitude change when observing the coherent PLD compared to the inverted or scrambled. In addition, the second period of change was revealed between

230, and 360 ms showing a larger amplitude in the right hemisphere when participants observed the coherent PLD compared to inverted or scrambled PLDs. A source localisation analysis suggested the earlier component was generated in the right fusiform gyrus whereas, the second component was generated in the right superior temporal gyrus. Based on the source, the authors suggest the first component was driven by attentional mechanisms of visual processing of the sudden onset of the dots. Whereas, the second component may represent the integration of the PLD's socially relevant information. These temporal dynamics have been replicated by both EEG and MEG data (Masahiro Hirai & Hiraki, 2006; Isik, Tacchetti, & Poggio, 2017; Pavlova, Lutzenberger, Sokolov, Birbaumer, & Krägeloh-Mann, 2007) suggesting attention is engaged early by the onset of the PLD whereas, the PLDs social information is integrated at a later period.

The involvement of a simulation process during the observation of biological information has been measured using EEG and examining specific bands of neural oscillations. This differs from ERPs, as these analyses report changes in power within a specified frequency band, while ERPs function in the temporal domain and do not include frequency domain information. An index of sensorimotor engagement can be measured using EEG, specifically by examining changes in the so-called 'mu' rhythm first described as "rolandic rhythm en arceau" (Gastaut, Terzian, & Gastaut, 1952). This rhythm has a frequency of approximately 8 - 13 Hz recorded over the sensorimotor regions of the brain (electrode sites, C3, C1, Cz, C2, C4) (Hobson & Bishop, 2017). Typically, when at rest, neurons at this site fire synchronously, however, during the observation of action (such as grasping) or conducting an action, the neurons in the sensory-motor regions become desynchronised and reduce in overall power measured at the mu frequency range on the surface of the scalp. This decrease is suggested to be an index in increased cortical activity (Pfurtscheller & Lopes Da Silva, 1999). To localise the neural region and networks associated with mu desynchronisation,

simultaneous EEG and fMRI studies have been conducted and demonstrated that mu is negatively correlated with blood-oxygen-level-dependent (BOLD) signals from the pericentral cortex and supplementary motor cortex (Mizuhara, 2012; Ritter, Moosmann, & Villringer, 2009). In addition, Yin, Liu, and Ding (2016) demonstrated that mu power was negatively correlated with BOLD activity from the sensorimotor network, the AOC. Second, mu power correlated with BOLD from areas of the salience network, which includes the anterior cingulate cortex and anterior insula. Last, mu power was negatively correlated with BOLD from attentional control regions, such as the superior parietal lobule and intraparietal sulcus. The authors suggest that mu rhythm power is associated with multiple brain regions and networks, consistent with brain stimulation research that suggests mu power is inversely related to the excitability of the sensorimotor cortex. During transcranial direct current stimulation (TDCS) anodal stimulation of the primary motor cortex led to mu desynchronisation becoming enhanced during motor imagery, whereas cathodal stimulation of this area reduced mu desynchronisation (Matsumoto et al., 2010). Taken together, the mu rhythm is considered a reliable index of sensorimotor engagement during the observation or execution of motion.

A considerable amount has been published on mu desynchronisation during action execution or the passive observation of faces, body parts, and hand movements in situations of social or object interaction (for review, see, Fox et al., 2016). Experimental paradigms examining changes in the mu rhythm typically have a participant either execute or observe an action, which results in a decrease in the amplitude at the mu frequency, compared to baseline measures (e.g., Cuevas, Cannon, Yoo, & Fox, 2014; Silas, Levy, & Holmes, 2012; Silas, Levy, Nielsen, Slade, & Holmes, 2010). Recent reviews (Bowman et al., 2017; Fox et al., 2016; Hobson & Bishop, 2017) have put forth recommendations to improve experimental designs when measuring mu desynchronisation. Another interesting finding when examining mu is individual differences, specifically sex differences. A meta-analysis conducted by Fox et al., (2016) suggests that males and females show differences in mu desynchronisation, with males

showing a stronger desynchronisation. However, the samples were biased towards men and studies investigating sex differences report that females show a more pronounced mu desynchronisation during the observation of biological motion (Cheng et al., 2008; Cheng, Tzeng, Decety, Imada, & Hsieh, 2006; Silas et al., 2010) while, Hobson and Bishop, (2016) found no sex differences in mu desynchronisation. Last, mu desynchronisation has been suggested to be influenced by an individual's trait empathy levels as measured by questionnaires (Woodruff, Martin, & Bilyk, 2011). Although, these correlations have been criticised for being small or not using the appropriate corrections during analysis (Hobson & Bishop, 2016). For example, Silas and colleagues (2010) demonstrated that when appropriate statistical corrections are used, empathy measures are unrelated to the desynchronisation of mu.

In terms of biological motion, PLDs have been highlighted as a good method to investigate mu desynchronisation, as good control stimuli can be produced by manipulating the PLD (Hobson & Bishop, 2016). The perception and understanding of biological motion are dependent on social abilities (Pavlova, 2012), and as mentioned, it draws on neural regions that make up the AON (Caspers et al., 2010). There have been mixed results as to whether biological motion engages sensorimotor regions, Morin and Grèzes (2008) suggest the inferior frontal gyrus is not specialised for biological motion processing, instead of for movement in general. In addition, Morin and Grèzes (2008) found the dorsal and ventral premotor cortices (PMC) were recruited during the observation of biological actions compared with a static stimulus, but this recruitment was not consistent. Further, a meta-analysis by Van Overwalle and Baetens, (2009) suggests the movement of whole-bodies selectively recruits the posterior superior temporal sulcus (pSTS) and is lateralised to the right hemisphere. Whereas, motion from body-parts (e.g., hands, fingers, feet) recruits the PMC and intraparietal sulcus (IAP) and recruits both hemispheres. The authors suggest that body-parts engage the sensorimotor regions as they involve intentionality, such as moving an object from point A to point B. While

the whole-body movements are devoid of this goal-directed action. However, this meta-analysis was restricted to using fMRI to measure the engagement of sensorimotor regions.

EEG studies demonstrate mu desynchronisation during the observation of biological motion from whole-body PLDs. Early evidence was presented by Ulloa and Pineda, (2007) who presented participants with videos of PLDs as either point of lights randomised (scrambled) or of a human figure conducting one of two actions, kicking or jumping. Compared to baseline, there was a desynchronisation to mu when observing the PLD of a human figure conducting an action, while scrambled PLDs did not. The study suggests that mu desynchronisation is independent of movement type (jumping jacks or kicking actions) and desynchronisation is symmetrical across hemispheres (electrodes C3 and C4). In addition, Perry, Troje, and Bentin (2010) explored the influence of social information exhibited by a coherent PLD on mu desynchronisation. Specifically, examining whether, focusing attention on social dimensions (emotions and intentions) would engage a simulation process, eliciting greater mu desynchronisation than when focusing attention on the PLDs sex. In this task, participants observed PLDs with different emotional states (happy or sad), intentions (moving forward or away from the observer) and with two sexes, either male or female. The observation of PLDs remains consistent for 1000 ms per block. During this observation period, the participants' task was manipulated; participants were asked to count rare events, depending on the block either the change in the PLD sex, intention or emotional state. Mu desynchronisation was greater for the intention condition compared to the emotion or gender condition. In addition, it was found that compared the central electrodes (C3, Cz, C4) there was a greater desynchronisation in the occipital electrodes (O1, Oz, O2). Taken together, social information modulates mu desynchronisation with biological motion containing intent, eliciting greater mu desynchronisation. Second, the authors highlight the influence of attentional mechanisms external to the motor system, play a role during the observation of biological motion, which can be dissociated dissociable by examining desynchronisation at occipital and central sites.

The perception of biological motion and mu desynchronisation can be influenced by other faculties. For example, Kéri and Benedek (2009) demonstrated the influence of hormones; in their study, participants were administered a placebo, or a neuropeptide called oxytocin, that is associated with social abilities (Insel & Fernald, 2004). The participants then observed a coherent PLD walking or a non-biological stimulus (a rotating square) both masked by dynamic noise and were then asked to respond if the dynamic noise contained target stimulus. The group that was administered oxytocin identified the PLD in the dynamic more accurately than the placebo group; whereas, the same was not true for the rotating square. Thus, suggesting that oxytocin modulates the perception of socially relevant stimuli. This neuropeptide can also influence mu desynchronisation during the observation of biological motion; relative to the placebo group, the group-administered oxytocin showed a significantly enhanced desynchronisation in low-alpha (O1, Oz, O2), mu (C3, Cz, C4) and beta rhythm (F3, Fz, F4) (Perry et al., 2010). Working memory (WM) can also influence perception and mu desynchronisation. In a series of studies, Gao, Bentin, and Shen (2015) explored the mechanisms that aid in holding biological motion in WM, as visual perception and WM share similar processing mechanisms when processing the same information (Ester, Rademaker, & Sprague, 2016; Ester, Serences, & Awh, 2009). The authors examined sensorimotor processing by recording EEG and examining the mu rhythm. The findings suggest that participants can remember three to four biological motion stimuli. In addition, mu desynchronisation increased in conjunction with memory load, which ended after more than four biological motion stimuli had been displayed. The study also found that mu desynchronisation was greater at central sites (C3, Cz, C4) relative to occipital (O1, Oz, O2). In addition, mu desynchronisation correlated with the number of biological motion stimuli but not non-biological stimuli.

Recently, Hobson and Bishop (2016; 2017) discussed issues when conducting mu desynchronisation research. First, adequate sample size: past research examining changes in

the mu rhythm lack a sufficient sample size. Using G*Power (Franz Faul, Erdfelder, Lang, & Buchner, 2007) a software program that determines an adequate sample size to detect a given effect size with some degree of certainty, the authors demonstrated that to find a medium effect size it is argued that a minimum of 40 participants is required, whilst for an interaction, 47 participants are required (Hobson & Bishop, 2016). Second, studies investigating mu desynchronisation during the observation of biological motion have found larger desynchronisation in occipital cites (Perry & Troje, 2010). Therefore, there have been concerns raised as to whether mu can be reliably distinguished from changes in the alpha rhythm. The mu rhythm shares the same frequency as alpha 8-13 Hz, the alpha rhythm which has been noted to become suppressed over occipital sites (O1, Oz, O2) (Perry & Bentin, 2011; Sadaghiani & Kleinschmidt, 2016).

The alpha rhythm is thought to represent cortical idling (Pfurtscheller, Stancák, & Neuper, 1996) and inhibition of task-irrelevant processes (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003). In addition, alpha desynchronisation has been found when attending to visual signals that require mental effort. Alpha synchronisation has been suggested to be a mechanism for ignoring unwanted information in the visual field to enhance processing at the attended area (Snyder & Foxe, 2010). In addition, alpha oscillations induced utilising transcranial magnetic stimulation (TMS) can reduce the observer's ability to detect visual targets in the hemisphere contralateral to the stimulated hemisphere (Romei, Gross, & Thut, 2010). In spatial attention tasks, the deployment of attention to a position in visual space, in preparation for the stimulus onset, causes lateralisation of alpha-band EEG amplitude in the posterior scalp regions. The two rhythms are separated based on topography; however, alpha activity may still inflate mu rhythm by occipital electrodes propagating forward to the central electrodes (Cohen, 2019; Luck, 2005). Thus research examining changes in mu should report both central and occipital sites (Perry & Bentin, 2009; Perry, Troje, et al., 2010).

Another issue when conducting mu research has been the selection of a baseline period where mu should not be engaged, so that the experimental manipulation, such as the onset of a stimulus, can take place and be compared to this unengaged period. There are various methods for measuring a baseline: for example, a single long-baseline recording may be used for all trials — alternatively, a within-trial baseline where each trial has its own baseline. A comparison of three methods suggests that a within-trial baseline is a better method as it was the most consistent sensorimotor activity (Hobson & Bishop, 2017). Similarly, what the participants are doing during the recording of the baseline may influence recording. If participants sit for long periods with and without stimulation (auditory or visual) alpha may become engaged due to attentional disengagement which can inflate this baseline period as the two rhythms share a frequency (e.g., Oberman et al., 2005). Another method has been recording a one-second baseline, with participants staring at a fixation cross prior, or the static first frame of the video prior to the start of a trial (e.g., Muthukumaraswamy, Johnson, Gaetz, & Cheyne, 2006). This method reduces removes the long-term effects of EEG such as sweating and reduces the attentional inflation of the baseline as attention does not become disengaged.

A recent review by Fox et al. (2016) has highlighted a lack of studies examining the temporal changes in mu desynchronisation. An example of highlighting the temporal changes was conducted by Brown, Wiersema, Pourtois, and Brüne, (2013), who examined mu desynchronisation, in a reward and punishment situation. Participants viewed videos from either a first- or third-person perspective and viewed videos of different bowls having a currency placed in them, dependant on the bowl it was placed the participant would either gain, lose or have no change in their reward. During analysis, the change in the mu desynchronisation was examined finding significant desynchronisation from the onset of the video to 3.5-4 seconds after onset. Revealing that for the engagement of sensorimotor regions as indicated by mu suppression, 3.5 seconds are required in this task. There are different time-

frequency methods, used to determine the power at a specified frequency for a given period. Although, these techniques involve a trade-off between temporal and spectral precision. The study as mentioned earlier used a Fast Fourier Transform (FFT), their common methods are a complex wavelet convolution and Hilbert filter that involved isolating a narrow temporal window of data to extract the associated frequency spectrum (Cohen, 2014; 2019). Another technique that provides similar advantages to the others mentioned; however, the precision is linked to the sampling rate of the recorded EEG data. A Complex Demodulation (CD) initially decomposes the complex signal into two constitutive parts of different phase; sine and cosine. These constitutive parts are multiplied by what is known as a modulation operation. The accuracy of frequency and temporal measures is dependent upon the sample rate of the recorded EEG data. This method calculates power, based on pre-event baseline and values are given as a percentage change from the baseline which allows for the legitimate inference of event-related desynchronisation or synchronisation (Pfurtscheller & Berghold, 1989; Pfurtscheller, Brunner, Schlögl, & Lopes da Silva, 2006; Pfurtscheller & Lopes Da Silva, 1999).

In line with the recommendations proposed by Hobson and Bishop (2016; 2017), Siqi-Liu and colleagues (2018) used high-density EEG to examine mu desynchronisation during the observation of biological motion enacted by a coherent PLD. The PLD enacted everyday actions with different emotions, either neutral or emotional (happy, sad, angry); they either had a human form or were scrambled. The observers were presented each video clip for three seconds and completed a one-back task to ensure attentive viewing: participants monitored for the immediate repetition of each video (i.e., the same configuration and movement of the dots, presented twice in a row); participants were explicitly instructed to look for an exact repetition of the dot configurations and their local motion. The study used both time-frequency and ERPs to analyse the EEG data. ERPs were used to examine whether experimental conditions elicited differential neural responses. This revealed a greater increase in amplitude toward coherent PLDs compared to scrambled, with the differences emerging

288-330 ms post-stimulus onset. The time-frequency analysis compared differences in the mu rhythm defined between 9 and 12 Hz. Coherent PLDs elicited greater mu desynchronisation compared to the scrambled PLDs. Further, the analysis revealed the desynchronisation of the mu rhythm occurred between 1000-2000 ms post-stimulus onset. The authors conclude that the PLDs with social information engaged a simulation process as they elicited greater mu than alpha-band desynchronisation. To the author's knowledge, this is the first study that has used time-frequency measures in conjunction with PLDs providing insight into the temporal changes during observation.

The previous sections demonstrate two periods of neural changes (early and late) that are observed during the observation of biological motion. First, attention; PLDs can orientate an observer's attention in space and are processed rapidly, within 200 ms. Second, the integration of the observed actor's motion features into an action. However, what remains unexplored is whether biological motion can exogenously capture the observer's attention using an abrupt cue in a peripheral location (Frischen, Bayliss, & Tipper, 2007). Also, does this engage sensorimotor processing as indexed by the mu rhythm, and is it modulated according to the direction of attention. For example, when spatial attention is engaged, the alpha rhythm in cortical visual regions are modulated in accordance with the direction that one's attention is shifted to. Specifically, the alpha rhythm is desynchronised when the directional cue (e.g., left) is contralateral to the hemisphere doing that processing (e.g., right) (Chica, Botta, Lupiáñez, & Bartolomeo, 2012; Thut, Nietzel, & Brandt, 2006). Conversely, when ipsilateral, that is when the direction of the cue (e.g., left) is in the same side as the hemisphere (e.g., left) the alpha rhythm becomes synchronised (Kelly, Lalor, Reilly, & Foxe, 2006). While, there is considerably more research that has examined the modulation of alpha (Romei et al., 2010; Vincenzo Romei, Rihs, Brodbeck, & Thut, 2008; Worden, Foxe, Wang, & Simpson, 2000), less has explored the modulation of the mu rhythm.

The modulation of the mu rhythm has been explored using somatosensory stimulation in spatial cueing paradigms. Anderson and Ding (2011) had participants attend to a fixation cross in the centre of a computer screen, and they were then informed to direct their attention either to their right, left or to both hands. After participants allocated their attention, the median nerve on the left or right was stimulated. The subjects were instructed to count and report the number of times the hand they were instructed to attend to was stimulated and ignore the stimulation if it was delivered to the hand that they were not attending to. Findings show a decrease in the mu rhythm (electrodes CP3, CP4) over the somatosensory cortex; specifically, a decrease in the hemisphere contralateral to the hand that attention was directed to, demonstrating the modulation of the mu rhythm, over somatosensory regions when attention is endogenously directed. What remains unknown is whether, the same finding would be true when attention is exogenously captured, specifically by a display of biological motion compared to random motion. Exploring this gap in the literature not only has theoretical implications to the understanding of biological motion processing but practical applications in workplaces. Neuroergonomic evaluations can improve tasks that utilise footage of human movements. For example, better technological designs or improved training schemes can aid in CCTV surveillance or crowd control tasks (Thompson & Parasuraman, 2012). Furthermore, these insights can assist in the development of computer vision systems capable of understanding motion, such as in automatic detection, identification and categorisation. It has been proposed that increased understanding of the neural mechanisms underlying the processing of biological motion can support the development of computer vision systems and computation models of action perception (Cichy & Teng, 2017).

To explore these questions, a variation of a spatial cueing paradigm, which is used in the assessment of attentional bias to certain stimuli was employed. The visual dot-probe task developed by MacLeod, Mathews, and Tata (1986) is one of the most widely used research tools for the objective measurement of attentional bias. During the visual-dot probe task

participants are presented with two cues (e.g., faces, sounds, bodies) that differ in some form of content (e.g., emotional or non-emotional) simultaneously in two opposing spatial directions (e.g., left vs right). The cues then disappear, and a target is then displayed in one of the two spatial locations. Participants respond by pressing a button indicating the spatial location of the target with accuracy and reaction times being measured. Variations may also present a forced-choice discrimination task, between two different targets such as the direction of an arrow (e.g., Stevens, Rist, & Gerlach, 2009). If the participants' RTs are shorter to the target that replaces one cue compared to the other, it is thought that this reflects an attentional bias towards that cue. A broad range of research has used the task with a diversity of cues (faces, objects, bodies), stimulus onset asynchrony (SOA) and populations (clinical and non-clinical) (for review, see Bantin et al., 2016; Bar-Haim et al., 2007; Frewen, Dozois, Joanisse, & Neufeld, 2008).

Summary

Biological motion can convey a range of social information, preferentially attended to across species and cultures with an important role in survival. In addition, it interacts with different cognitive systems, such as attention and working memory. The evidence reviewed suggests that local aspects of whole-bodies, (such as gaze, hand direction etc.) can direct spatial attention, although, the paradigms that have been generally implemented present the bodies as central targets that cue spatial attention. However, to the author's knowledge, there has been no research examining whether coherent biological motion preferentially captures spatial attention compared to incoherent biological motion. Hence, the use of the attention bias task is proposed to measure whether biological motion from an upright coherent PLD would preferentially capture the observer's attention compared to a scrambled PLD. In addition, to examine the underlying neural mechanisms and the relationship between sensorimotor engagement and spatial attention, EEG will be recorded to measure modulations in power at the mu frequency as an index of sensorimotor engagement (Hobson & Bishop, 2016).

Aims & predictions

This current study aims to examine whether biological motion exogenously captures spatial attention and, in turn, modulates sensorimotor simulation. An attention bias task is used to examine this by bilaterally presenting two PLDs, one with a coherent human form for biological motion and the second of the same walker but scrambled for non-biological motion. It is expected that the coherent PLD will preferentially capture attention, with significantly lower reaction times to targets that replace the coherent PLD compared to when they replace the scrambled PLD. In addition, to explore whether local motion processing was engaged, regardless of which PLD preferentially captures attention, the walking direction should significantly reduce reaction times when the direction is the same as the target location. Third, sensorimotor engagement will be examined by measuring EEG during the presentation of motion. Specifically, the mu rhythm 8 - 13 Hz will be examined; it is expected that there will be a significant decrease in mu amplitude if attention is biased to the coherent PLD, this decrease will be greater at central cites compared to an alpha decrease over the occipital lobe. In addition, due to the nature of the dot-probe paradigm, I expect bilateral differences in mu desynchronisation as predicted, with a greater decrease in hemispheres which the coherent PLD appears contralateral to. Last, it is expected that attention bias will correlate with mu desynchronisation.

Methods

Participants

To determine adequate sample size, I conducted an apriori power analysis using G*Power (F. Faul, ErdFelder, Lang, & Buchner, 2007). To decide on an effect size for the analysis, a review of studies using a dot-probe task was conducted (see., Appendix B). The effect sizes examined were based on behavioural data RTs and analysis was conducted using repeated measure ANOVAs. As not all studies do not report their effect sizes and for consistency all sizes were calculated as partial eta squared based on the reported F-values, using the following method: For example, if an articles reports $F(1, 20) = 6.00$, you can calculate that $\eta_p^2 = 6.00 * 1/(6.00 * 1 + 20) = 0.23$.

$$\eta p^2 = \frac{F * \text{dftime}}{F * \text{dferror} + \text{dftime}}$$

From the reviewed literature, the effect sizes range from medium to large. Large effect sizes are found in research employing emotion/threatening stimuli. A key issue is that the stimuli used are static images, with a short display time (100 - 200ms), making it is difficult to select an adequate effect size. Therefore, I decided to choose a conservative, medium effect size for ANOVA ($\eta^2 = 0.06$; Cohen, 1988).

A power analysis was conducted to determine the sample size for a 2x2x2 ANOVA, cued space (right or left), target location (right or left) and the PLDs walk direction (right or left) to detect a medium effect ($f = .25$, as outlined by Cohen, 1988), with a power of .90. Repeated measure ANOVAs are susceptible to violating the assumption of sphericity; hence, a conservative correction for non-sphericity was made, 1/ (number of measures - 1) = 0.2. The power analysis resulted in a minimum sample size of 56 to detect a medium effect size. As to my knowledge, there are no studies which implement this variation of the cueing paradigm exactly while, measuring mu/alpha power changes, thus behavioural data should be

used for the power analysis. Thus, the minimum sample size for EEG analysis was determined based on Hobson and Bishop (2016) recommendation of 40 participants.

A total of 63 first-year psychology students were recruited from a London University and were awarded course credits for their time. For the behavioural analysis, a total of 56 participants were included, with 7 excluded due to too many errors (> 15%). The final sample consisted of 22 males and 34 females, with a mean age of 22.7 (*SD* = 3.83; 18-36 years old). The sample included 46 right-handed participants, 8 left-handed participants and 2 ambidextrous participants, all self-reported.

For EEG analysis, a total of 18 participants were excluded. The exclusion of one participant was due to their data becoming corrupt, seven were removed due to failing the behavioural experiment, and ten participants had excessive muscle and eye blink artifacts during EEG recording causing a low number of trials (< 20). EEG analysis was conducted on forty-five participants after cleaning of the EEG data (described below), consisting of 18 males (*M* = 22.64, *SD* = 3.78) and 27 females (*M* = 22.68, *SD* = 3.84), 37 right-handed participants, 6 left-handed participants and 2 ambidextrous participants, all self-reported.

Procedure

Participants were seated in a dimly lit room at a distance of 65cm to a 17-inch computer screen. EEG sensors were then applied to the scalp. Participants completed a dot-probe paradigm, with the cues being videos of walking PLDs (cues described below). The task was presented electronically using the E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA). Before the task began, participants were informed to maintain focus on the fixation cross and to keep head movements to a minimum. They were briefed that dots will appear on both sides of the monitor, static and after some time some dots will disappear, and the remaining will begin to move (see fig. 3) then they will completely disappear, and the letter's

'M' or 'N' will appear on the left or right side. Participants were told they had to respond by pressing 'B' or 'H' dependant on whether the letter 'M' or 'N' appeared on the final screen.

The experiment contained 16 conditions, these conditions were a combination of different cue locations (left & right), target location (left & right), target type (M or N) and cue walk direction (left & right); each condition consisted of 24 trials. For each trial in the experiment, participants simultaneously viewed the coherent and scrambled PLD, with each either in the left or right visual space (see fig. 3). The PLDs were displayed from a sagittal view and walked either to the right or left. The PLD was then followed by a target, the letter's or 'N' if the target appeared in the same space as the coherent PLD it was considered a 'congruent' trial whereas, if it replaced the scrambled PLD it was considered an incongruent trial, regardless of the target. Participants conducted twenty practice, so they can familiarise themselves with PLDs, targets and the response keys, with a chance to ask questions; these data were not included in the analysis. A total of three blocks lasting approximately 10 – 15 minutes, each containing 128 trials giving a total of 384 trials throughout the experiment. At the start of each trial, static masked PLDs were displayed for 1000 ms, with a random inter-trial interval (ITI) of 1000 - 1500 ms was included between the onset the static images and onset of movement. Then unmasked PLD was displayed for 2000 ms, this time period was selected in order to allow for an adequate window to see mu desynchronisation (Siqi-Liu et al., 2018). Finally, a discrimination task until participants respond. Participants responded by pressing one of two centrally located keys ('B' and 'H' on the QWERTY keyboard for left and right responses respectively) with their index and middle fingers on the right (dominant) hand in order to reduce spatial compatibility effects or the Simon effect associated with bimanual responses. A discrimination task was used to maintain the participants' attention. Participants were required to respond to the letter 'N' or appearing either to the left or right of the screen after the cues. For counterbalancing, half of the participants responded by pressing 'B' for 'N' and 'H' for 'M'. The other half responded with 'H' for 'M' and 'B' for 'N'.

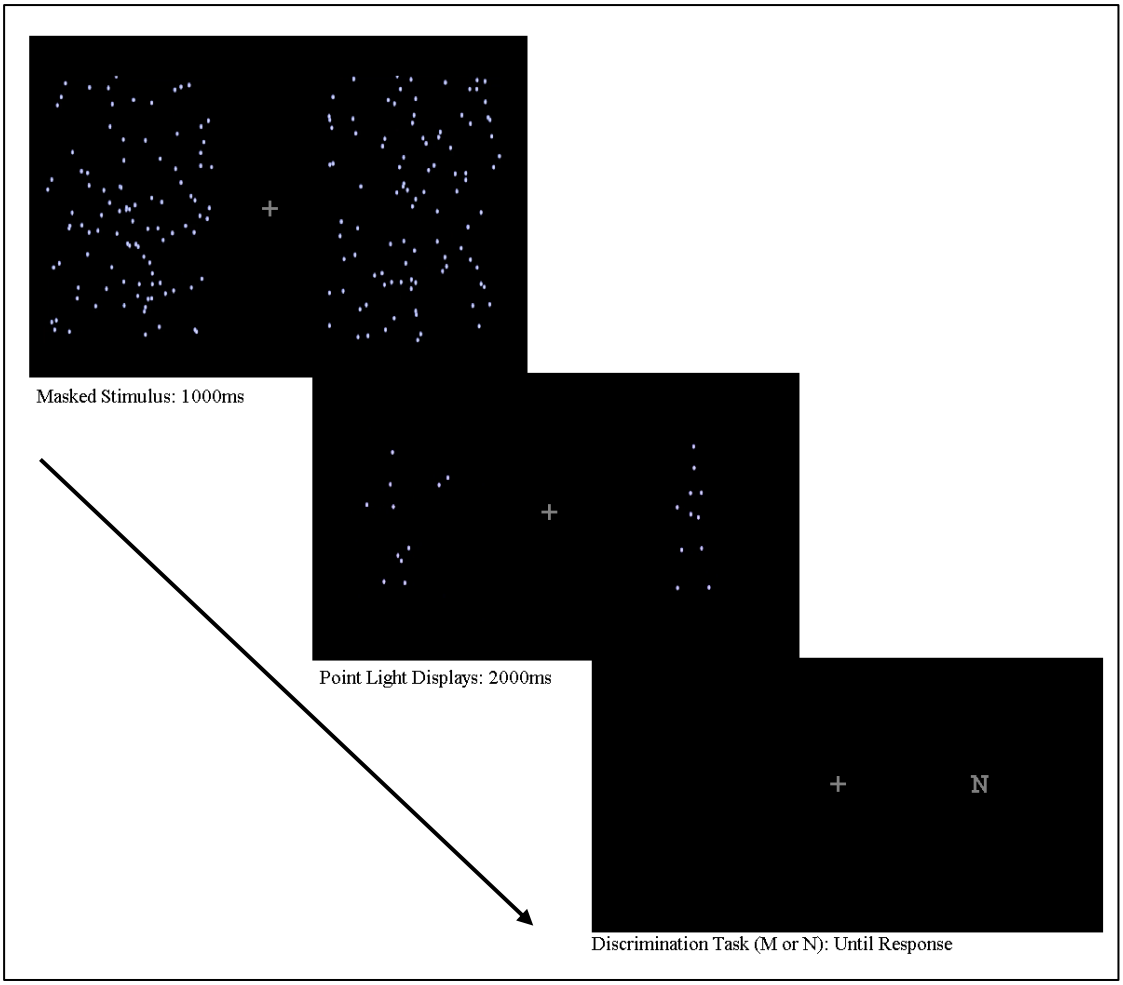


Fig 3. Static images of the experimental procedure. The first frame represents the baseline recording of static images of the moving cues the first frame displayed laterally, that was displayed for 1000 ms and had a random inter-trial onset for movement. The second image is the onset of movement, the dynamic noise is removed, and both the PLW and scrambled PLD begin walking a vertical speed either towards the left or right, for 2000 ms. Finally, the PLDs disappear and replaced by either the letter 'M' or 'N' either replacing the visual space occupied by either the coherent or scrambled PLD.

Stimuli

Point Light Cues

The cues used were produced by Troje & Westhoff (2006) https://www.biomotionlab.ca/bml-scramble). These cues were developed by averaging motion captured data from 100 participants (50 male & 50 female) with 11 markers placed on key joints, representing the head, one shoulder, one hip, the two elbows, two wrists, two knees, and two ankles. The biological motion was presented by coherent PLD with a human figure, walking at veridical speed, displayed from a sagittal view with gait frequencies were 0.93 Hz. The non-biological motion was the same figure, but each trajectory was placed at a random position within a 4.4x4.4-degree square in the centre of the display area. Scrambling the phase was implemented by replacing each dot's veridical phase with a phase picked randomly between 0 and 360 degrees. Scrambling the frequency was done by multiplying the veridical speed of the walker with a number between 0.5 and 2, picked randomly according to a uniform distribution on a logarithmic scale.

EEG Baseline

The baseline was recorded prior to the start of each trial. Participants were displayed the scrambled and non-scrambled PLDs as static images with the addition of dynamic noise, 1000 random points of lights. This avoids the sudden onset of visual stimuli that engages alpha desynchronisation. Each set of baseline images corresponded to the first frame of the moving PLD and matched the walking direction. Thus, there was a total of two sets of baseline images, scrambled and non-scrambled PLD facing either left or right (see fig. 3).

Data Analysis

Data Processing (behavioural)

Accuracy was counted as a response that correctly identified the type of target, and acted an attention check, ensuring participants were engaged with the visual stimuli. A conservative rejection criterion for accuracy scores was selected (15%). In addition, as a unique RT analysis 'windsorizing' would be conducted, to ensure a maximum number of trials were maintained per subject. Participants with an accuracy of less than 85% (58 missed trials) were removed from the final analysis. In addition, all missed trials were removed from the analysis. To remove outliers, traditionally the dot-probe literature removes outliers based on discrete a priori expectations of normal response time, for example including RTs between 200 - 2500ms or removing data points that are 2.5 SD greater or below the mean. However, modern statistical methods such as 'winsorizing' have been recommended to improve accuracy, maximise power and maintain all data points (Erceg-Hurn & Mirosevich, 2008). When 'winsorizing' is compared to the aforementioned discrete methods for outlier removal in a dot-probe task, it has been demonstrated to improve the reliability of bias scores and retain more data points (Price et al., 2015).

A winsorizing procedure was used to transform extreme values while minimising missing values in the data. Values outside 1.5 interquartile ranges from the 25th or 75th percentiles (the "Tukey Hinges") of the full distribution of RT values (across all individuals and all sessions) were rescaled to the last valid value within that range and then maintained as datapoints at these new, non-outlying values. In this experiment, the 75th percentile value of 935 ms, and interquartile range of 254 ms would be added. The interquartile value would be multiplied by 1.5, and the new value (381) is added to the 75th percentile value for a new value of 1316. Any value on the RT distribution above this would be rescaled to 1316 ms (the largest value in the distribution that is within the valid range). Whereas, for the 25th percentile, the interquartile value would be subtracted by 381 for a value of 300. Any value on the RT

distribution below this will be rescaled to 300 (the smallest value in the distribution that is within the valid range).

EEG acquisition and pre-processing

EEG (BioSemi Active Two system, Brain Products) was recorded from 64 electrodes at a sample rate of 2048 Hz, referenced to the CMS-DRL (common mode sense-driven right leg). The horizontal electrooculogram (HEOG) was recorded from the outer canthi of the eyes. Data were processed using Brain Electrical Source Analysis (BESA) and re-referenced to a common average. The offline data were filtered with a high-pass filter at 0.1 Hz to minimise slow drifts (Cohen, 2014) and no low-pass filters were applied in order to avoid distorting the power spectra (Luck, 2005). The data was then segmented to the cue-movement onset with a baseline period of -500 ms prior to cue onset and extended to 2000 ms at target onset. The whole EEG recording for each participant's data was then checked for artefacts using an automatic algorithm from the BESA software. The algorithm rejected any epoch with voltages exceeding ± 60 μV or with an average of less than 0.1 μV, and any epoch with voltages that had a steeper gradient across the selected epoch than ± 0.75. Data sets were also examined visually to judge whether artefact contamination was due to regular and consistent blinking. If rejection was based on a high number of blinks, the blinks were modelled using a spherical head shape and dipole sources and removed from the waveforms. Electrodes where the amplitudes exceeded 250 μV were deemed 'bad' and were either rejected or interpolated if all surrounding electrodes were deemed 'good' (Silas et al., 2012).

Results

Behavioural Results:

Behavioural analysis on accuracy scores was not conducted as a conservative rejection criterion for missed trials was set at 15%, leading to a ceiling effect where accuracy scores showed little variance, prohibiting meaningful comparisons. Behavioural analysis was conducted on participants reaction time (RTs), that is the time between target (M or N) onset and the button press indicating which stimuli were presented. RTs on correct trials for each participant were averaged across trials, 48 trials per condition. A 2x2x2 repeated measures analysis of variance (ANOVA) was conducted on the reaction times, with a factor of the coherent PLD location (right or left), a factor of target location (right or left) and a factor of the PLDs walk direction (right and left) as within-subject variables. Participants accuracy was calculated as the percent of button presses correctly indicating the type of stimulus displayed. Accuracy was then evaluated statistically in the same fashion as response time, with a 2x2x2 repeated measures ANOVA having the same factors.

The ANOVA on RTs showed one interaction effect; there were no main or other interaction effects (all Fs < 3.322, all ps > .05). There was an interaction effect between the location of the coherent PLD and the location of the target, F (1, 55) = 40.003, p = .001, $\eta\varrho^2$ = .421. Post-hoc comparisons were conducted by means of pairwise-sample t-tests, to control for type 1 errors due to multiple comparisons; a Bonferroni correction was applied, resulting in a new alpha level of .008. Paired sample t-tests revealed three differences in RTs (see fig. 4), first for when the target replaced the target in the left visual field (t (55) = 4.044, p = .001). Participants had lower RTs when target replaced the scramble PLD (M = 819.92, SD = 146.59) compared to when it replaced the coherent PLD (M = 833.60, SD = .146.60). Second, there was a significant difference for when the target appeared in the right visual field (t (55) = 5.714, p = .001). Participants responses were lower when the target replaced the scramble PLD in the left visual field (M = 819.52, SD = 145.55) compared to when the target replaced the coherent

PLD in the left visual field (M = 84.44, SD = 151.74). Last, there were differences in RTs when the coherent PLD was presented on the right and the scramble PLD on the left (t (55) = 3.022, p = .004). There was a significant difference when the target replaced the scrambled PLD on the right (M = 819.53, SD = 146.60) compared to when it replaced the coherent PLD in the same space (M = 841.44, SD = 151.74). No other differences were found, all ps > .008.

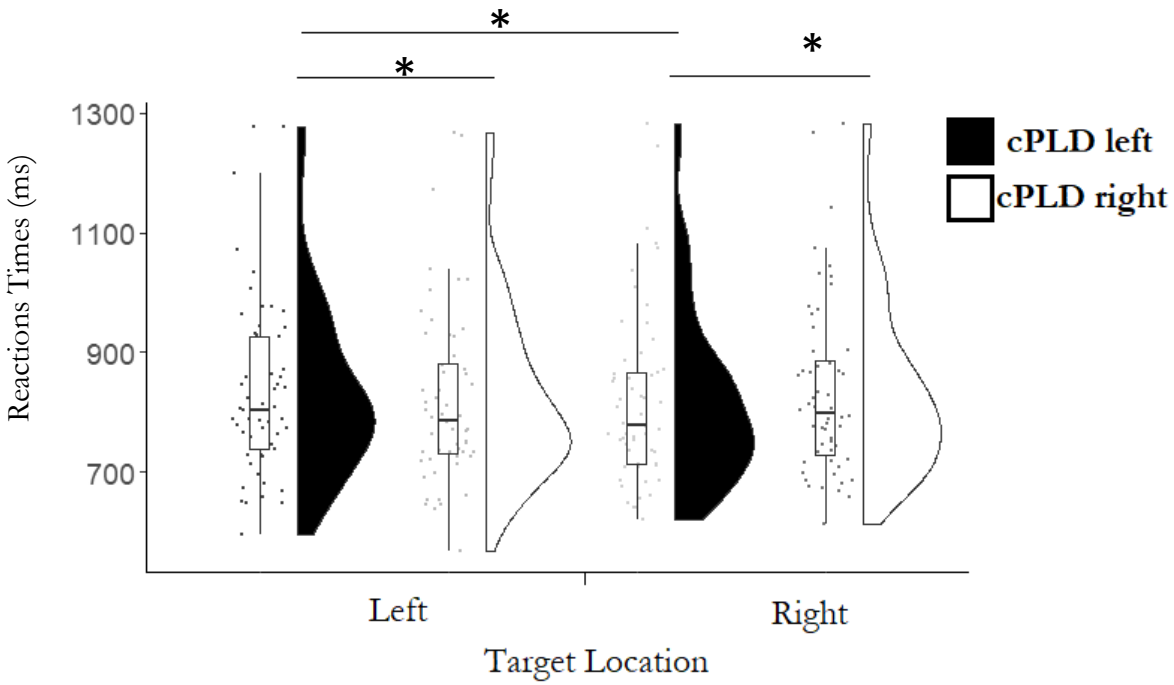


Fig 4. Raincloud plots of RTs for responses to targets as a function of the coherent PLD (cPLD) location. Boxes represent the mean ± Standard Deviation. Raincloud plots represent the density and spread of all contributing data points (Allen, Poggiali, Whitaker, Marshall, & Kievit, 2019). * = p < .008

EEG Analysis

EEG data were analysed using continuous time-frequency analysis (complex demodulation) to analyse the modulation of power during movement observation. The temporal resolution was set at 50 ms, with a frequency resolution of 1 Hz. A lower frequency cut off 4 Hz, and higher frequency cut off 20 Hz. The analysis was conducted on the two central electrodes, C3 and C4 and two occipital electrodes O1 and O2.

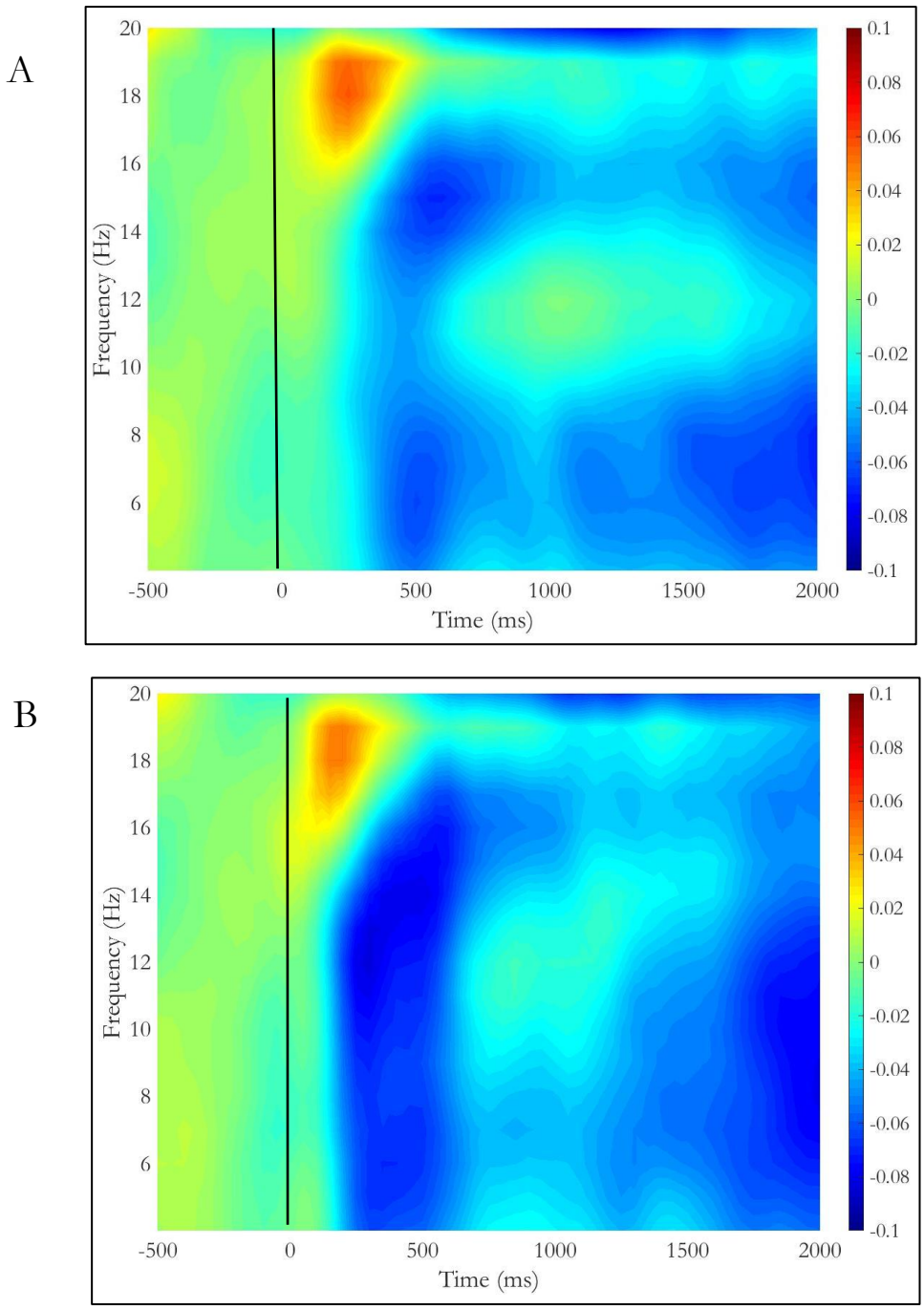


Fig 5. Average amplitude spectrum power for a 2500 ms period, from the baseline, beginning at -500 to movement onset at time 0 and then target onset at time point 2000. Both images are smoothed, with image A displays the grand average for central electrodes (C3 & C4) and image B displays the grand average for the occipital electrodes (O1 & O2).

Analysis of periods

To extract time-periods for statistical analysis and hybrid approach was taken, combining hypothesis and data-driven approaches to extract relevant power for further statistical analysis. First, the frequency domain was chosen, data from the 8 - 13 Hz range was extracted as this frequency is implicated with the rolandic mu rhythm and alpha rhythm (see, Fox et al., 2016; Hobson & Bishop, 2016; 2017). For the time domain, all data points, for each condition were extracted, from the baseline -500 ms to target onset 2000 ms the total period extracted was 2000 ms (see fig. 5), for the frequency of 8 - 13 Hz, using in-house MATLAB script. The frequency data were then averaged at 50 ms time periods for a total of 51 time periods. To define the time period for statistical analysis, a series of one-sample t-tests were against a value of zero were conducted, a standard approach in defining mu activity (Oberman et al., 2005; Silas et al., 2010; 2012), on the averaged data between 8 - 13 Hz for central electrodes (C3 & C4) and occipital electrodes (O1 & O2) between -500 - 2000 ms. If five tests in a row were significant ($p < .05$), then all data from the first significant test were extracted until there was no longer a significant difference or reached 2000 ms when the target replaced the cues (see., Koelewijn, van Schie, Bekkering, Oostenveld, & Jensen, 2008). The data for the time period was then averaged and used in subsequent ANOVAs. The one-sample t-tests, for data averaged across all conditions, found significant differences between 350 - 900 ms and between 1150 - 2000 ms post cue onset (all $ts < 2.192$, all $ps < .05$). A second one-sample t-test was conducted for the averaged 8 - 13 Hz for occipital electrodes finding significant differences for the time period 200 - 1100 ms and again between 1250 - 2000 ms post-stimulus onset (all $ts < 2.011$, all $ps < .05$).

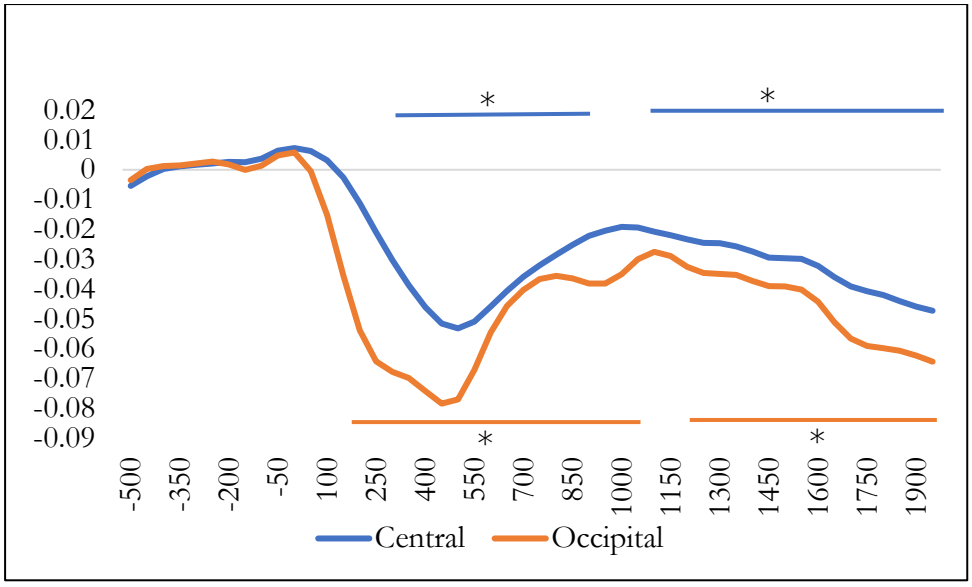


Fig 6. Central (C3 & C4) and Occipital (O1 & O2) electrodes average amplitude from baseline period to target onset period for a total of 2000 ms. Baseline begins at -500, then followed by movement onset at time 0 and target onset at 2000. * = $p < .05$

Statistical Analysis of Time Regions

Four separate 2x2x2x2 ANOVAs were conducted using the different time periods, early central (350 - 900ms), late central (1150 - 2000), early occipital (200 - 1100) and late occipital (1250 - 2000). All ANOVAs had the same factors, first a factor of the topographical site (central or occipital), a factor of the hemisphere (left or right), a factor of visual space of where the coherent PLD was located (left or right) and a factor of PLD walk direction (left or right).

The ANOVA for the early central period revealed two main effects and one interaction effect, no other effects were found (all $Fs < 1.673$, all $ps > .05$). The first main effect revealed a significant difference in amplitude between the left and right hemisphere F (1, 44) = 5.199, $p = .028$, $\eta\varrho^2 = .106$. There was a greater decrease in the left hemisphere (M = -.05, SE = .013) compared to the right hemisphere (M = -.04, SE = .012). The second main effect was for the visual space the coherent PLD occupied F (1, 44) = 8.499, $p = .006$, $\eta\varrho^2 = .162$. There was a greater decrease in amplitude when the coherent PLD appeared in the participants right and

the scrambled PLD appeared in the left visual field (M = -.05, SE = .013) compared to when the coherent PLD appeared in the left visual field and the scrambled PLD occupied the right visual field (M = -.04, SE = .013). Last, there was an interaction effect between the topographical site and hemisphere, F (1, 44) = 9.762, p = .003, $\eta\rho^2$ = .182. Post-hoc comparisons where conducted by means of paired sample t-tests, alpha was corrected using a Bonferroni correction (α = .008). The t-tests (t (44) = 3.924, p = .001) revealed a greater decrease in the left hemisphere for the central electrode (M = -.06, SD = .07) compared to the central electrode on the right hemisphere (M = -.02, SE = .08).

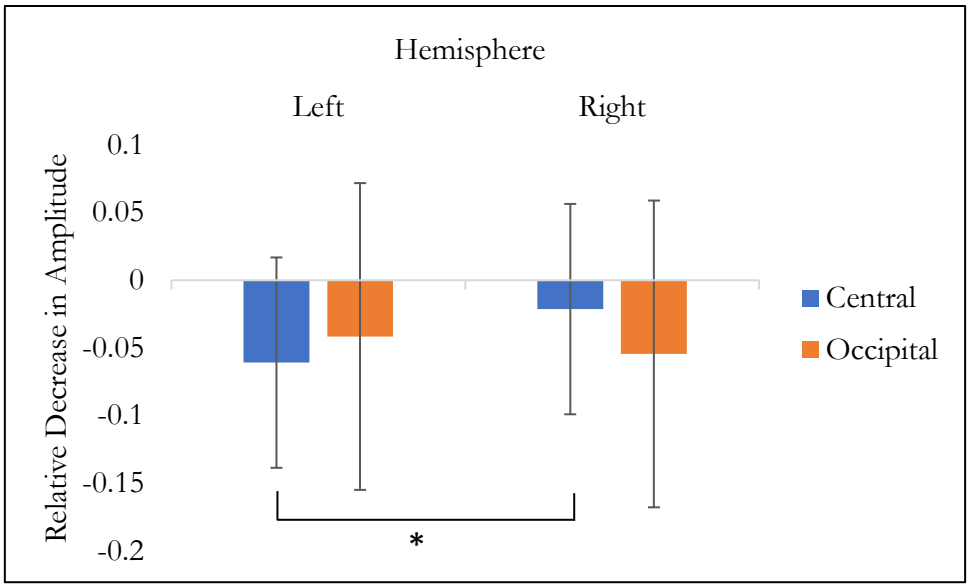


Fig 7. A graph displaying the mean decrease of amplitude in central and occipital electrodes positioned on the left and right hemisphere. Error bars represent standard deviation.

The ANOVA the late central period, revealed two main effects and one interaction effect, no other effects were found (all Fs < 2.469, all ps > .05). The first main effect was significant differences in amplitude between the left and right hemisphere F (1, 44) = 24.945, p = .001, $\eta\rho^2$ = .362. There was a greater decrease in the left hemisphere (M = -.05, SE = .012) compared to the right hemisphere (M = -.02, SE = .012). The second main effect was for the PLD walk direction F (1, 44) = 4.961, p = .006, $\eta\rho^2$ = .031. There was a greater decrease in amplitude when the PLDs walked towards the right (M = -.04, SE = .012) compared to when

they walked towards the left (M = -.03, SE = .012). Last, there was an interaction effect between the topographical site and hemisphere, F (1, 44) = 7.832, p = .008, $\eta\varrho^2$ = .151. Post-hoc comparisons where conducted by means of paired sample t-tests, alpha was corrected using a Bonferroni correction (α = .008). The t-tests (t (44) = 5.072, p = .001), revealed a greater decrease in the left hemisphere for the central electrode (M = -.06, SD = .06) compared to the electrode on the right hemisphere (M = -.01, SD = .09).

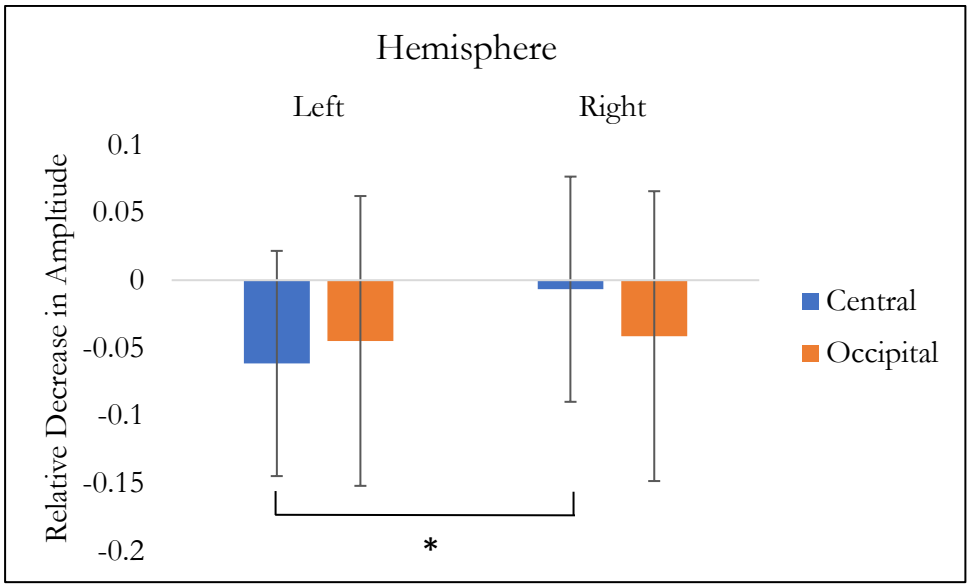


Fig 8. A graph displaying the mean decrease of amplitude in central and occipital electrodes positioned on the left and right hemisphere. Error bars represent standard deviation.

The ANOVA for an early occipital period, revealed one main effect and one interaction effect, no other main or interaction effects were found (all Fs < 3.226, all ps > .05). The main effect was for the location of the coherent PLD, F (1, 44) = 5.326, p = .026, $\eta\varrho^2$ = .108. There was a greater decrease in amplitude when the coherent PLD appeared in the participant's right visual field (M = -.06, SE = .14) compared to when it appeared in the left visual field (M = -.04, SE = .13). The interaction effect was between hemisphere and topographical site. Post-hoc comparisons were conducted by means of paired sample t-tests, alpha was corrected using a Bonferroni correction (α = .008). The t-tests (t (44) = 3.574, p =

.001) revealed a greater decrease in the left hemisphere for the central electrode (M = -.06, SD = .08) compared to the electrode on the right hemisphere (M = -.02, SD = .08).

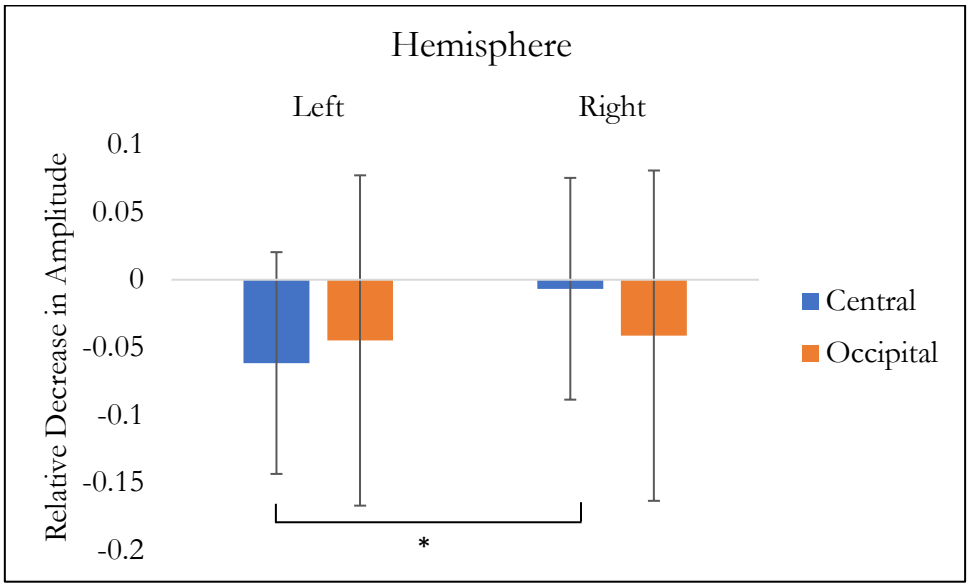


Fig 9. A graph displaying the mean decrease of amplitude in central and occipital electrodes positioned on the left and right hemisphere. Error bars represent standard deviation.

The ANOVA for the late occipital time period, revealed one main effect and one interaction effect, no other main or interaction effects were found (all Fs < 3.226, all ps > .15). The main effect was for the hemisphere, F (1, 44) = 25.151, p = .001, $\eta\varrho^2$ = .364. There was a greater decrease in amplitude when the coherent PLD appeared in the left hemisphere (M = -.07, SE = .13) compared to the right hemisphere (M = -.03, SE = .14). The interaction effect was between hemisphere and topographical site. Post-hoc comparisons were conducted by means of paired sample t-tests, alpha was corrected using a Bonferroni correction (α = .008). The t-tests (t (44) = 5.399, p = .001) revealed a greater decrease in the left hemisphere for the central electrode (M = -.08, SD = .06) compared to the electrode on the right hemisphere (M = -.01, SD = .11). In addition, there was a significant difference between the central electrode on the right hemisphere compared to the occipital electrode on the left hemisphere (t (44) = 3.043, p = .004). There was a greater decrease in the occipital electrode on the left hemisphere

(*M* = -.06, *SD* = .12) compared to the central electrode on the right hemisphere (*M* = -.01, *SD* = .11).

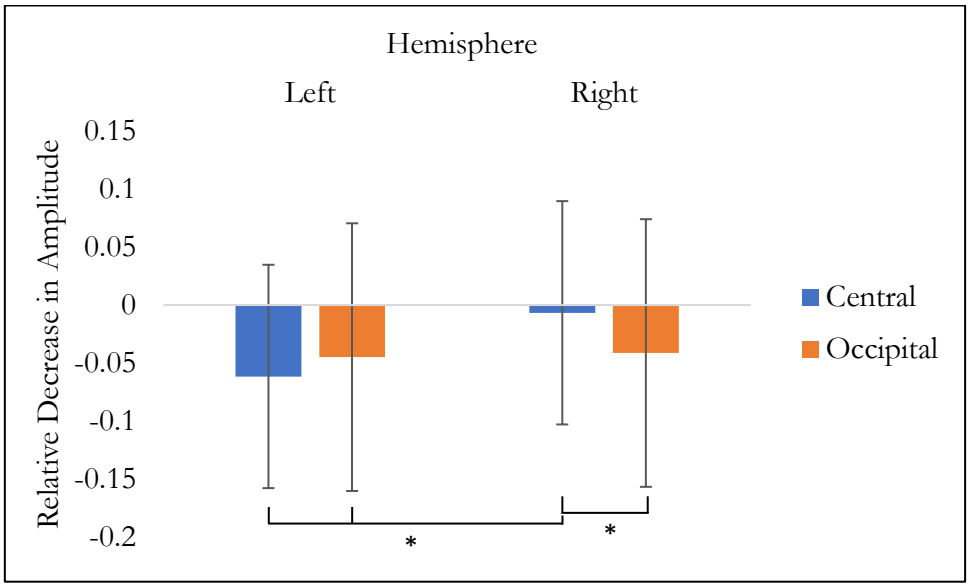


Fig 10. A graph displaying the mean decrease of amplitude in central and occipital electrodes positioned on the left and right hemisphere. Error bars represent standard deviation.

To investigate for lateralisation in neural activity, the electrodes were averaged relative to their position during the onset and display of the cue. For example, when the coherent PLD was displayed in the left visual field ipsilateral to electrode C3, this was averaged with electrode C4 when the coherent PLD was displayed in the right visual field. The same was done for C3 and C4 when the coherent PLD was contralateral to the electrode; the same was done for the occipital electrodes O1 and O2. Two sets of pairwise t-tests were conducted on averaged data for central electrodes (C3 & C4) and occipital electrodes (O1 & O2) comparing power at the 8-13 Hz frequency bandwidth between contralateral and ipsilateral to the position of the coherent PLD. As was conducted in the one-sample t-tests, a period was extracted if five consecutive time-windows were significant ($p > .05$). T-tests for the central electrodes revealed no five-consecutive time-windows were significant (all $ts > 2.232$, all $ps > .031$). The occipital electrodes also did not reveal five consecutive significant time-windows (all $ts > 2.099$, all $ps > .042$).

Attention Bias and mu desynchronisation

To examine whether attention bias correlates with mu desynchronisation, data for RTs and for EEG from both time-periods were extracted and transformed into an index of attention bias and mu following suggestions by Thut, Nietzel, Brandt and Pascual-Leone (2006). An index was calculated by averaging each central electrode (C3 & C4) across the time period of interest. To incorporate both hemispheres, the following formula was used, which results in a negative when mu desynchronisation is greater in the left hemisphere compared to the right hemisphere and positive when the opposite is the case.

$$\text{Index (mu)} = \frac{\text{mu (Right Hemisphere)} - \text{mu (Left Hemisphere)}}{\text{Mean of mu (Right + Left Hemisphere)}}$$

To create an index of attention bias, behavioural responses based on RTs for left and right targets were considered and transformed using the following formula which results in negative values when responses were faster for targets presented in the left visual field compared to the right visual field and positive values for when the opposite is the case.

$$\text{Index (RT)} = \frac{\text{RT (Left target)} - \text{RT (Right Target)}}{\text{Mean of RT (left + Right target)}}$$

Pearson's correlation analysis was computed to assess the relationship between indices of attention bias and mu desynchronisation. There was no correlation between indices of mu desynchronisation and attention bias (all $rs < .01$, all $ps > .05$).

Discussion

The current experiment explored whether exogenous spatial attention was biased toward biological motion, represented by a coherent human figure PLD compared to a non-biological motion represented by a scrambled PLD. An attention bias task was used which assumes that faster responses to the target reflect the selective deployment of exogenous spatial attention allocation to a cue preceding that target at the same location (Bantin et al., 2016). The findings of the behavioural data reveal a smaller RT and increased accuracy when responding to targets that replace the scrambled PLD compared to the coherent PLD. Taken together, this finding suggests there was an attentional bias towards the scrambled PLD. Moreover, the analysis of the EEG data revealed decreases in early and late time periods in central mu and occipital alpha. Across all conditions, there was a left hemisphere bias, with greater mu desynchronisation at central sites in the left compared to the right hemisphere. The indices of mu desynchronisation did not correlate with indices of an attention bias from the behavioural data.

Contrary to my prediction, the participants' attention was biased towards the non-biological motion compared to the biological motion; here, I will offer a speculative explanation for this unexpected finding. First, it may be that the scrambled PLD preferentially captured attention as it was an ambiguous movement. For example, Heier, Simmel, and College (1944) demonstrated that when subjects viewed shapes moving and interacting with each other, these participants inferred intentions and personality traits to them. Similarly, due to the ambiguity of the scrambled PLD, participants may have been anthropomorphising the scrambled motion. A second possible interpretation of faster responses to targets replacing scrambled PLDs is related to the cue duration in this paradigm being a longer duration (2000 ms), compared to traditional dot-probe paradigms (Bantin et al., 2016). Thus, the findings can be considered in relation to the literature on Inhibition of Return (IOR). IOR effect is

considered to have taken place when RTs become longer when responding to targets in the cued location compared to the uncued location, which has been reported to begin with a cue-target interval of 225 ms and can last up to 3000 ms (Klein, 2000). For an IOR to occur, it is assumed that attention first must reflexively shift to a particular location and subsequently disengage from that location. There is then a delayed response to the target that is presented in the location which attention previously disengaged from. However, IOR effects have predominately been noted in traditional Posner cueing paradigms, where one location is space is cued, it has also been found when using the dot-probe paradigm (e.g., Bennett & Pratt, 2001; Theeuwes & Godijn, 2002). Theeuwes and Van der Stigchel (2006) used the occurrence of IOR to demonstrate that faces preferentially engage attention when presented bilaterally with a non-biological item (e.g., phone). The authors demonstrated a delayed saccade to the location a face previously occupied. However, as the current study did not measure eye movements, and there is a lack of literature examining attention bias to movement, it is difficult to determine which interpretation explains the current studies finding. Thus, the current study either demonstrates attention is biased but towards non-biological motion or an attention bias towards biological motion.

Third, it was predicted that the PLDs walk direction would contribute to shifting the observer's attention. Walk direction, can be discerned from either a coherent PLD or from a scrambled PLD as it is carried by the local motion of the walker (Troje & Westhoff, 2006). Contrary to my prediction, walking direction from either PLD did not influence participants response times or accuracy when responding to the subsequent target. Prior research examining walk direction presents a single sagittal PLD centrally, having observers identify the walk direction (Troje & Westhoff, 2006), as an endogenous cue (Ding et al., 2017). To the author's knowledge, this is the first study to explore walk direction in a spatial paradigm, presenting the PLDs in peripheral space. This finding indicates that when PLDs are presented

peripherally, they are processed by their global form and not by the local motion of the dots of light.

Conversely, the PLDs walk direction did influence the EEG data. It was revealed to induce greater mu desynchronisation when the coherent and scramble PLD walked toward the right compared to when they walked to the left. It is difficult to interpret this finding as it did not coincide with any behavioural differences or relate to lateralised desynchronisation of central mu or occipital alpha (Lange, Pavlidou, & Schnitzler, 2015). Further, it should be noted that the effect size for this finding is small (Cohen, 1988); thus it's interpretation is beyond the scope of the current study and should be considered in future work.

EEG data also showed temporally specific changes, while no specific predictions were set about temporal differences there were some noteworthy differences. Consistent with prior research, a decrease in occipital alpha is noted at 200 ms (Hirai & Hiraki, 2005; Isik et al., 2017; Jokisch et al., 2005). In addition, the decrease in occipital alpha is prolonged, ending at 1100 ms, whereas, central mu lasted until 900 ms. Desynchronisation of occipital alpha is symmetrical regardless of PLD locations. Thus, indicating that motion alone is capable of inducing changes in visual attention-related brain activity regardless of the form that carries said motion, in this study, a human or scramble form. This would explain why electrodes at occipital sites recorded greater desynchronisation than central electrodes (see fig. 7). This finding appears to contradict the view that occipital regions are sensitive to the structure of the PLD, as it has been reported that changes in occipital amplitude are larger in responses to coherent than scrambled PLDs (Hirai & Hiraki, 2006).

Interestingly, the experiment revealed an earlier desynchronisation in the central mu rhythm post-cue onset, at 350 ms. This differs from prior work, which uses time-frequency analysis, which report mu desynchronisation to a single centrally position PLD at 1000 ms post-cue onset (Siqi-Liu et al., 2018). However, this may be due to the complexity of

information carried by the PLD. In this study, the PLDs were neutral with one type of motion, while PLDs with varying social information induce varying magnitudes of mu desynchronisation (Perry et al., 2010). A second later time-window of significant desynchronisation in occipital alpha and central mu emerged. However, differences began earlier at central sites beginning at 1150 ms whereas occipital decreases were noted as 1250 ms; with both remaining decreased until the target onset. The decrease at this period is smaller compared to the first period (see fig. 7) however, may support the interpretation of an IOR effect which will be discussed together with the lateralisation of the mu rhythm.

In terms of the EEG findings in this study, I set out to explore whether central mu rhythm would be modulated by spatial attention. Thus, it was expected that mu desynchronisation would be lateralised depending on the visual space the coherent PLD occupied. The EEG analysis reveals a left hemisphere bias independent of PLD locations. Further, analysis suggests this bias is primarily driven by topographical differences at the central sites; with a greater decrease in electrode C3 compared to C4. However, the same difference did not occur for electrodes at occipital sites which showed a bilateral desynchronisation as both visual fields.

Hemispheric biases during the measurement of mu desynchronisation have been noted to be dependent on motor involvement (Aziz-Zadeh, Koski, Zaidel, Mazziotta, & Iacoboni, 2006). Perry, Stein, and Bentin (2011) report a bias in electrode C3 when subjects are moving their hands in response to the observed stimuli with a contralateral difference as subjects were mostly right hand dominant. Thus, the bias in electrode C3 may be a consequence of the sample being largely right-handed and using their dominant hand to respond to the target, with the decrease in C3 may reflecting anticipatory motor preparation for target onset: as the sample size is skewed to right-handed participants it not possible to conduct any posthoc comparisons between the two groups. However, this explanation does not account for the early

desynchronisation in the mu rhythm beginning at 350 ms (see fig. 6). It seems likely that if the decrease were a consequence of motor preparation for the target, it would be in a period closer to target onset.

Similarly, examining frequency bands outside of the examined 8 - 13 Hz there is desynchronisation of the low beta bandwidth (16 - 20 Hz) and theta bandwidth (3 - 8 Hz) (see fig. 5). With the former in particular becoming desynchronised by imagined, observed and executed movement (Babiloni et al., 2002; McFarland, Miner, Vaughan, & Wolpaw, 2000; Zaepffel, Trachel, Kilavik, & Brochier, 2013). For example, Cooper, Simpson, Till, Simmons, and Puzzo, (2013) displayed participants hand movements for short (3 seconds) or long periods (80 seconds) and found greater the low beta rhythm was modulated during the observation of hand movements compared to static or non-biological motion. The changes in the beta rhythm were greater than in the mu range, suggesting the beta rhythm may be a more reliable index of sensorimotor engagement for short presentation periods of movement. Taken together, the size of desynchronisation in the left hemisphere, specifically in electrode C3 may have been amplified by motor preparation in the later periods.

The behavioural results demonstrated an attention bias to non-biological motion, with lower RTs to targets that replaced the scrambled PLD. Further, the EEG results show two significant time-periods (an early and late) for both occipital and central sites. Taking these two findings into consideration together, I will offer an alternate explanation, albeit speculative. The first explanation is based on the absence of any inhibitory effect as neither the occipital or central rhythm showed synchronisation. The occipital alpha is bilaterally desynchronised in response to both spatial regions containing visual information (Rihs, Michel, & Thut, 2007).

Interestingly, central mu is desynchronised at both hemisphere locations showing no synchronisation of mu in response to the location the scramble PLD occupied which has been reported to occur during the observation of scrambled PLDs (Ulloa & Pineda, 2007). Thus,

the scrambled PLD may have elicited mu desynchronisation as it was in the peripheral vision and was ambiguous enough to engage sensorimotor systems (Giromini, Porcelli, Viglione, Parolin, & Pineda, 2010). Thus, both the coherent and scramble PLD elicited mu desynchronisation independent of attention bias, as this did not correlate with desynchronisation.

The two early time-periods extracted (early central and occipital) revealed a greater desynchronisation when the coherent PLD occupied the right visual field and the scrambled PLD occupied the left visual field (see fig. 7). In contrast, the second time-window for the central electrodes shows the opposite with a greater synchronisation when the coherent PLD occupied the left visual field and scrambled occupies the right visual field. When discussing these differences, the central electrode on the right hemisphere will be considered as its counterpart has a larger magnitude of desynchronisation, which is possibly amplified by motor preparation in hand response. Examination of the central electrode for the right hemisphere shows, there is a greater decrease in the first period when the coherent PLD is contralateral. This diminishes in the second time-period when the scramble PLD is now contralateral to the central electrode on the right hemisphere (see fig. 8), which may be an indication of the IOR effect discussed in relation to the behavioural results, with the early time-period reflecting engagement to the coherent PLD and disengagement in the period in between where no significant differences in occipital alpha and central mu are reported.

The findings of this study have to be seen in light of some limitations. One issue is with the attention bias paradigm implemented and how to interpret the direction of the result (Salemink, van den Hout, & Kindt, 2007). In this study, the behavioural data is unclear whether there is a bias towards the scramble or coherent PLD due to an IOR effect thus, it is difficult to interpret the results of the attention bias task. In addition, the attention bias task has been widely criticised as an unreliable measure of attention bias, with one issue on using RTs as an

index of attention bias (Chapman, Devue, & Grimshaw, 2019; Kappenman, Farrens, Luck, & Proudfit, 2014; Puls & Rothermund, 2018; Thigpen, Gruss, Garcia, Herring, & Keil, 2018). Although, the current study incorporated statistical methods to overcome issues with the handling of outliers in RTs, as recommended by Price et al., (2015), it is recommended that future research examining attention bias should implement additional measurements. For example, ERPs or eye-tracking data have been suggested alongside RT measurements (Torrence & Troup, 2018), as RTs alone have been suggested to be unreliable (Bantin et al., 2016). An additional limitation was the EEG analysis was influenced by a manual response; future research should aim to use a vocal response in order to remove the influence of manual response on central electrode desynchronisation. Taken together, future research should clarify whether an attention bias to non-biological motion exists using alternate experimental tasks. In addition, the experimental task if used in conjunction with EEG should avoid a manual response that will influence central electrode recordings.

Conclusion

The current study examined whether spatial attention exogenously captures attention. Second, it used EEG to examine whether the spatial attention modulated the mu rhythm defined between the bandwidth 8 – 13 Hz over the central sites. The experiment revealed significantly smaller RTs and greater accuracy in responses to targets which subsequently replaced the scrambled PLD. Two suggestions are proposed to explain this finding. However, in conjunction with temporal changes in the EEG data, an IOR effect is seen; with attention rapidly locating to the coherent PLD and disengaging with inhibited re-engagement to the coherent PLD. Further, spatial attention did not modulate the central mu rhythm. Instead, a hemispheric bias was revealed, specifically in left hemisphere at central sites. This bias is argued to partially reflect motor preparation in anticipation of target onset. Last, there was no relationship between behavioural indices of attention bias and mu desynchronisation.

Appendix A

Information Sheet

Information sheet

Dr Alexander Jones
Dr Jonathan Silas
Themis Efthimiou

Psychology Department
Middlesex University
Hendon
London NW4 4BT

Attention allocation and threat perception during the observation of biological motion: An EEG study

You are being invited to take part in a research study. Before you decide to participate, it is important for you to understand why the research is being done and what it will involve. Please take your time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything that is not clear or if you would like more information. Take your time to decide whether you wish to take part.

The purpose of the research

This research is aimed at providing us with a better understanding of how our brain attends to biological motion. Past research has shown humans have a preference for biological motion (the movement of living organisms) and are able to identify gender and emotional state from biological information alone. Although, the brain mechanisms behind this and the role of the mirror neuron system (MNS) are unclear. Therefore, we want to measure your brain activity during the observation of biological motion.

What will happen to me if I take part?

The experiment should take no longer than 90 minutes and will be conducted in a dedicated psychophysiology laboratory. There are two aspects to the experiment which will be explained below:

Visual Display:
You will be seated in front of a monitor where you will maintain focus on the centre of the screen. Video images will be displayed for a short period, thereafter an image will appear. You will be asked to respond by responding on the keyboard, to the location of the screen the image appeared.

Electroencephalography (EEG):
EEG involves placing small electrodes the surface of your scalp; they record small electrical activity. Electrodes may also be placed on your earlobes and/or your forehead, or to either side of your eyes, to measure eye-movements. To achieve good level of conductance, your skin may be cleaned with alcohol before these electrodes are attached. To get a good connection between the scalp and electrodes a conductive gel will be used. This gel is specifically manufactured to be used for EEG testing such as this and is very unlikely to cause any irritation. However, it should not be used on damaged skin or if you have a history of skin allergies. Specific details of the content of the gel are available and you can try a small amount of gel on your arm first if you wish to test what it feels like. This gel washes out very easily with warm water, and shower facilities, a towel to dry your hair, and a hairdryer will be provided.

Consent

You will be asked to sign a consent form prior to taking part in the research. It is important that you are aware that **participation in this research is entirely voluntary**. You do not have to take part if you do not want to. If you decide to take part, **you may withdraw at any time during your participation without giving a reason**. You may withdraw your data up until data analysis begins in which will be in June 2018.

All data relating to your participation in this study will be held and processed in the strictest confidence, in accordance with the Data Protection Act (1998). All data will be held securely in password protected computer files and locked filing cabinets. Your identity will not be passed on to anyone who is not directly involved in this study and will be protected in the publication of any findings. However, we may also, if you consent, contact you again after the study and ask if you want to take part in a follow up experiment. However, you can decide then if you wish to take part again.

All proposals for research using human participants are reviewed by an Ethics Committee before they can proceed. The Middlesex Psychology Department's Ethics Committee have reviewed and approved this proposal.

Thank you for taking the time to read the information sheet. If you require advice, information or reassurance about a technical or health related matter, or have a concern about any other aspect of your participation, please raise this with one of the investigators:

Investigator Contact Details:

Dr Alexander Jones

Psychology Department
Middlesex University
The Burroughs
Hendon
London
NW4 LBT
a.j.jones@mdx.ac.uk
Tel: 0208 411 6328

Dr Jonathan Silas

Psychology Department
Middlesex University
The Burroughs
Hendon
London
NW4 LBT
j.e.silas@mdx.ac.uk
Tel: 0208 411 4546

Consent Form

Participant Identification Number:

CONSENT FORM

Title of Project: Attention allocation and threat perception during the observation of biological motion: An EEG study

	Please initial box
1. I confirm that I have read and understand the information sheet dated ……..…… for the above study. I have had the opportunity to ask questions and have been given contact details for the researcher(s)	1
2. I understand that my participation is voluntary, the data collected during the research will not be identifiable, and I am free to withdraw my consent without giving a reason	2
3. I agree that this form that bears my name and signature may be seen by a designated auditor (i.e. a Chair of the Psychology Ethics Committee or representative of the University Ethics Committee) to monitor correctness of procedure	3
4. I agree that my non-identifiable research data may be stored in National Archives and used anonymously by others for future research. I am assured that the confidentiality of my data will be upheld through the removal of any personal identifiers	4
5. I understand that the data I provide may be used for analysis and subsequent publication, and provide my consent that this might occur	5
6. I agree to take part in the above study	6

_____	_____	_____
Name of participant	Date	Signature
_____	_____	_____
Name of person taking consent (if different from researcher)	Date	Signature
_____	_____	_____
Researcher	Date	Signature

Dr Alexander Jones

Psychology Department
Middlesex University
The Burroughs
Hendon
London
NW4 LBT
a.j.jones@mdx.ac.uk
Tel: 0208 411 6328

Dr Jonathan Silas

Psychology Department
Middlesex University
The Burroughs
Hendon
London
NW4 LBT
j.e.silas@mdx.ac.uk
Tel: 0208 411 4546

Debriefing

Psychology Department
Middlesex University
Hendon
London NW4 4BT

Dr Alexander Jones
Dr Jonathan Silas
Themis Efthimiou

Attention allocation and threat perception during the observation of biological motion: An EEG study

Thank you very much for taking part in our study, we greatly appreciate your contribution. This study was interested in finding out whether displaying biological motion would bias your spatial attention to that side of the screen. Second, we measure your brain rhythms using EEG in order to identify the role of central alpha 'Mu' wave during the observation of biological motion.

You are more than welcome to discuss your feelings about taking part in the experiment with the experimenter before leaving especially if you have any concerns. If you have any questions or anything you'd like to discuss about the procedure after you leave please feel free to contact the lead investigators. If you wish to find out more about the results of the study once the data has been analysed then send an email to one of the lead investigators, below.

Dr Alexander Jones

Psychology Department
Middlesex University
The Burroughs
Hendon
London
NW4 LBT
a.j.jones@mdx.ac.uk
Tel: 0208 411 6328

Dr Jonathan Silas

Psychology Department
Middlesex University
The Burroughs
Hendon
London
NW4 LBT
j.e.silas@mdx.ac.uk
Tel: 0208 411 4546

Appendix B

Instructions

Version 1.

Welcome to the experiment

A letter will appear either on the Right or Left side of the screen

The image will either be a N or M

If a N appears PRESS H

If a M appears PRESS B

Let's begin with some practice

Press SPACE to begin

Version 2.

Welcome to the experiment

A letter will appear either on the Right or Left side of the screen

The image will either be a N or M

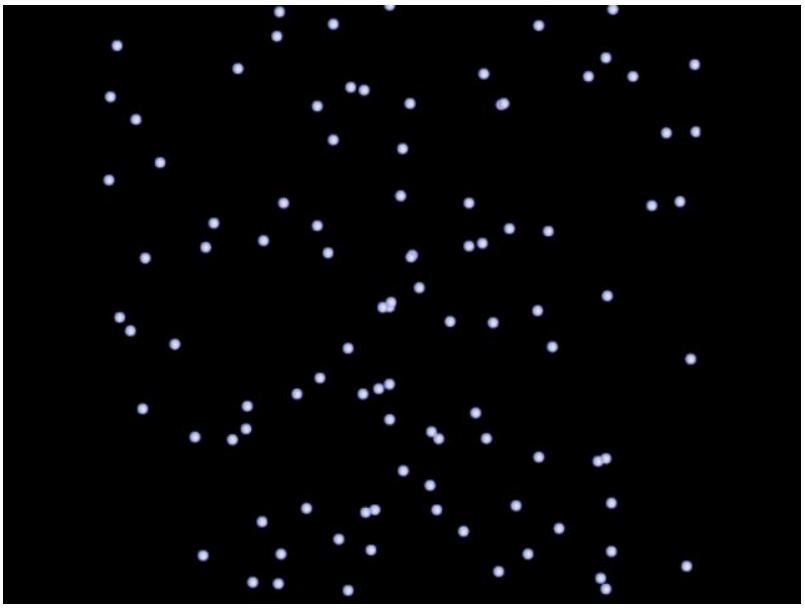
If a N appears PRESS B

If a M appears PRESS H

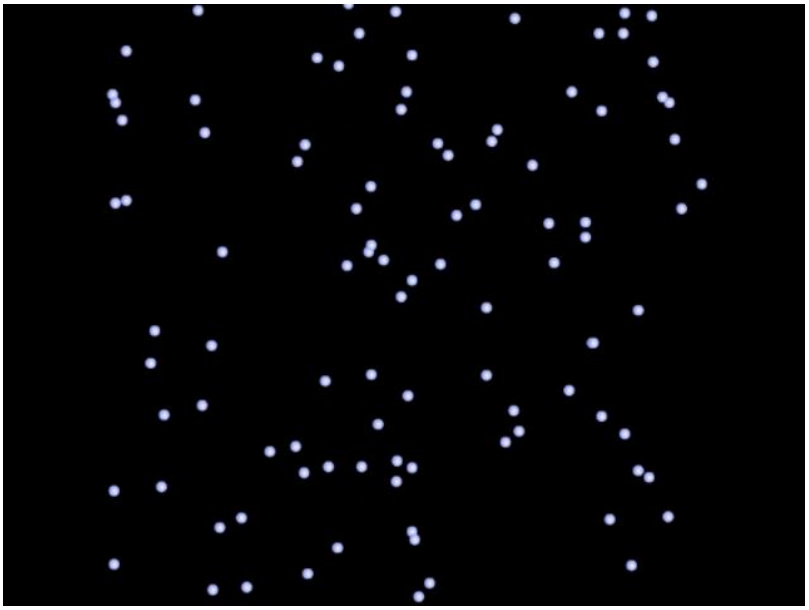
Let's begin with some practice

Press SPACE to begin

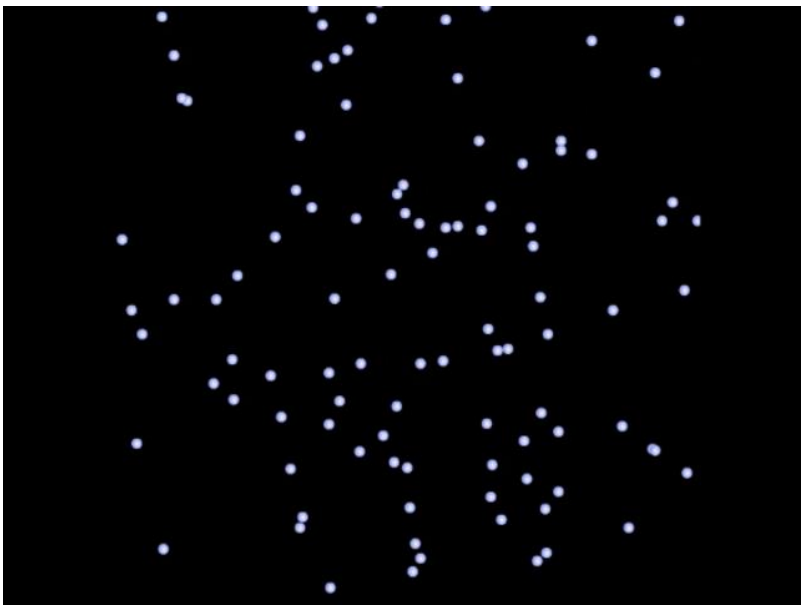
First frame of baseline images, coherent PLD walking to the left masked by 100 random dots of noise. Demo display of movement can be viewed at: https://www.biomotionlab.ca/bml-sc



First frame of baseline images, coherent PLD walking to the right masked by 100 random dots of noise. Demo display of movement can be viewed at: https://www.biomotionlab.ca/bml-sc



First frame of baseline images, scrambled PLD walking to the left masked by 100 random dots of noise. Demo display of movement can be viewed at: https://www.biomotionlab.ca/bml-sc



First frame of baseline images, scrambled PLD walking to the left masked by 100 random dots of noise. Demo display of movement can be viewed at: https://www.biomotionlab.ca/bml-sc

Sample Size Power Analysis

The sample size was decided by conducting a priori analysis using G*Power (F. Faul et al., 2007). To decide on an effect size for the priori analysis, a review of studies using the dot-probe paradigm was conducted. The effect sizes are based on behavioural data, reaction times, using repeated measure ANOVAs. As not all studies report their effect sizes and for consistency all sizes were calculated as partial eta squared based on the reported F-values, using the following method: For example, if an articles gives $F(1, 20) = 6.00$, you can calculate that $\eta_p^2 = 6.00 * 1/(6.00 * 1 + 20) = 0.23$.

Study:	**Cues:**	**Analysis:**	**Effect Size η_p^2:**
(Thigpen et al., 2018)	Faces (Neutral V Angry)	ANOVA	.23
(Adams & Kleck, 2005)	Faces (Neutral V Angry)	ANOVA	.09
(Blechert, Ansorge, & Tuschen-Caffier, 2010)	Bodies	ANOVA	.14
(Kappenman, MacNamara, & Proudfit, 2013)	Objects (Neutral V Threat)	ANOVA	.36
(Bocanegra, Huijding, & Zeelenberg, 2012)	Faces (Fearful V Neutral)	ANOVA	.21

From the reviewed literature, the effect sizes range from medium to large. Large effect sizes are found in research employing emotion/threatening stimuli. A key issue is that the stimuli used are static images, with a short display time (100-200 ms), making it is difficult to select an adequate effect size. As finding comparable research to the current study is difficult, I have decided to choose a conservative, medium effect size for ANOVA ($\eta^2 = 0.06$; Cohen J., 1988).

A power analysis was conducted to determine the sample size for a 2x2x2 ANOVA with a factor of target location (right and left), coherent PLD location (right and left) and PLDs walk direction (right and left) to detect a medium effect (f = .25, as outlined by Cohen J., 1988), with a power of .90. Repeated measure ANOVAs are susceptible to violating the assumption of sphericity, hence, a conservative correction for non-sphericity was made, 1/(number of measures-1) = 0.2. The power analysis resulted in a sample size of 56 to detect a medium effect size.

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